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SPONSORED PROJECT INITIATION

Date: 12 September 1979

Project Title: A Geophysical Investigation of the Seismicity of the Clark Hill Reservoir Vicinity Green card

Project No: G-35-662 (Follow-on to G-35-633, G-35-622 and G-35-616)

Project Director: Dr. Leland T. Long

Sponsor: U. S. Nuclear Regulatory Commission Energy

Agreement Period: From 1 May 1979 Until ~~30 April 1980~~ 10/31/80

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8,750 GIT (G-35-345) contract of which $8,750 is budgeted for Mod. No. 7)
$42,644 TOTAL

Reports Required: Quarterly Progress Reports; Annual Progress Reports; Final Report; Publications Preprints; Publications Reprints.

Sponsor Contact Person (s):

Technical Matters

Contractual Matters
(thru OCA)

Kellogg V. Morton, Chief
Research Contracts Branch
Division of Contracts
Office of Administration
U. S. Nuclear Regulatory Commission
Washington, D. C. 20555

Defense Priority Rating: None

Assigned to: Geophysical Sciences (School/Laboratory)

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GEORGIA INSTITUTE OF TECHNOLOGY

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SPONSORED PROJECT TERMINATION/CLOSEOUT SHEET

Date 3/28/84

Project No. G-35-662

School/~~Lab~~ Geo. Sci.

Includes Subproject No.(s)

Project Director(s) Dr. Leland T. Long ~~GTRI~~ / GIT

Sponsor U.S. Nuclear Regulatory Commission

Title A Geophysical Investigation of the Seismicity of Clark Hill Reservoir Vicinity

Effective Completion Date: 10/31/80 (Performance) 10/31/80 (Reports)

Grant/Contract Closeout Actions Remaining:

- [ ] None
- [x] Final Invoice or Final Fiscal Report
- [ ] Closing Documents
- [ ] Final Report of Inventions
- [ ] Govt. Property Inventory & Related Certificate
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Continues Project No. G-35-633, G-35-622, & G-35-616

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A GEOPHYSICAL INVESTIGATION OF THE SEISMICITY OF THE CLARK HILL RESERVOIR VICINITY

Preliminary Report No. 2

VERTICAL ELECTRIC SOUNDING WITH SCHLUMBERGER ELECTRODE ARRANGEMENT NEAR CLARK HILL RESERVOIR

for Project G35-633

School of Geophysical Sciences
Georgia Institute of Technology
Atlanta, Georgia 30332

March, 1980

Introduction:

In the aftershock zone of the August 2, 1974 earthquake, the aftershocks appear to be associated with prominent joint or schistosity planes. If water penetration is a significant factor in releasing stress energy, then water concentrations should be higher along zones where earthquakes are most pronounced. Since, water content has a strong influence on rock resistivity, a direct current resistivity study of the epicenter area was undertaken. Two depth soundings obtained during December 1978 have been analyzed and are documented in our previous report. Since the original analysis, two additional Schlumberger vertical electrical soundings were obtained, and two horizontal profiles were undertaken using a fixed electrode spacing. The purpose of this report is to present and analyze the new data.

Furthermore, a computer program for the automatic interpretation of Schlumberger sounding curves was obtained to aid in the data interpretation. This computer program, written by Zohdy (1973) is an iterative inversion procedure which utilizes the modified Dar Zurrouk curves for the inversion of Schlumberger electrical sounding curves. The data from the first two soundings (VES No. 1 and VES No. 2) are reinterpreted using this program, and the results are given in the appendix A. (Figure 10 and 11).

Vertical Electric Sounding

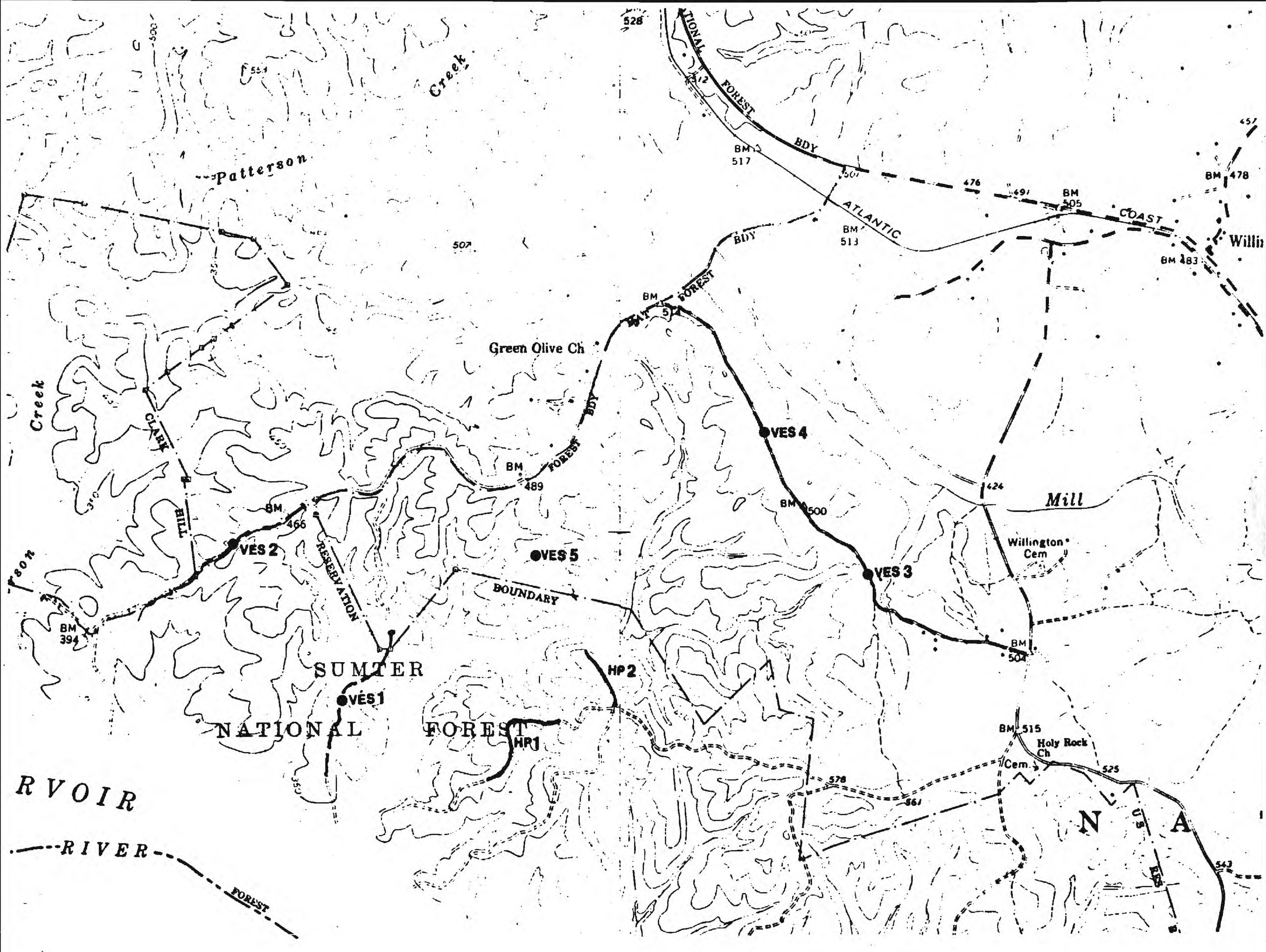
Two Schlumberger vertical electrical soundings (VES No. 3 and VES No. 4) were performed with a maximum current electrode separation of 1600 meters (AB/2 = 800 meters), along a dirt road, trending northwest, on the northeastern border of the epicenter area (Figure 1). These electrical soundings were positioned so that their centers were separated by 800 meters, a distance equal to the maximum value of AB/2.

VES No. 3

Vertical electrical sounding No. 3 was completed in two stages (see Tables 1a and 1b). The results of both stages are plotted in Figure 2. Since the data show scatter, a smooth curve was interpreted on the basis of a fit of the observation points to a three layer theoretical master curve. However, we have chosen to consider the smoothed curve to follow the observation points which were obtained with the shorter potential electrode spacings (MN) for current electrode spacing (AB/2) less than 400 meters as indicated in Figure 2. For longer current electrode spacing (AB/2 greater than 400 meters) the uncertainty in the data are large. An offset of the resistivity curve is observed for (AB/2) spacing greater than 400 meters.

The interpretation of VES No. 3 resistivity curve given in Figure 2 was done manually (through curve matching technique) and with the automatic interpretation provided by the computer program.

Figure 3 shows the fit of the smoothed observed data to a theoretical curve. The manual interpretation indicates a three layer case, with a nine meter thick resistive surface layer (77.5 ohm-m) overlying a lower resistivity (77.5 ohm-m) layer eighteen meters thick over a highly resistive



Patterson
Creek
Creek
CLARK
HILL
RESERVATION
BOUNDARY
FOREST BDY
ATLANTIC
COAST
Green Olive Ch
VES 1
VES 2
VES 3
VES 4
VES 5
HP 1
HP 2
BM 466
BM 489
BM 394
BM 517
BM 513
BM 505
BM 478
BM 483
BM 500
BM 504
BM 515
Mill
Willington Cem
Holy Rock Ch
Cem.
SUMTER
NATIONAL
FOREST
RVOIR
RIVER
FOREST
N
A
US
528
476
424
525
578
561
543

Resistivity Data Form

V.E.S. No. 3 1st trial

Operator: Hernandez & Smith

A B Direction:

Notes:

Location:

AB/2	MN	K	I	ΔV Scale	ΔV Reading	ρ
10	2	155.5	17.5	1.02	74.7	677.1
10	5	58.9	22.2	1.02	21.7	595.0
15	2	351.9	19	1.02	26.0	49[illegible].8
15	5	137.4	19	1.02	65.0	479.5
20	5	247.4	13.2	1.02	18.0	405.5
30	5	561.5	15.1	0.1	6[illegible]	214.1
40	5	1001.4	22.3	0.1	39.0	175.1
40	20	235.6	22.3	1.02	18.0	194.4
50	5	1555.9	24.3	0.1	31.5	206.0
50	20	377.0	24.3	1.02	13.0	206.5
70	20	754.0	28.4	1.02	10.0	27[illegible].8
100	20	1555.1	20.5	0.1	59.0	447.6
100	80	328.2	21.0	1.02	27.7	347.2
150	20	3513.6	19.3	0.1	35.0	638.1
150	80	820.7	19.3	1.02	13.0	565.6
200	20	6267.5	19.8	0.1	24.5	7[illegible].4
200	80	1509.6	19.8	1.02	[illegible]	775.8
300	20	14121.5	17.0[illegible]	0.1	18.0	1490.0
300	80	3471.5	17.0[illegible]	0.1	49.0	995.7
400	20	25117.0	23.6	0.1	14	1[illegible].0
400	80	6228.4	23.5	0.[illegible]	[illegible]	1614.7
400	200	2356.2				
500	20	39254.2				
500	80	9754.3				
500	200	3770.0				
650	80	16528.7				
650	200	6479.5				
800	80	2507.0				
800	200	9[illegible]9.6				

Table 1a. VES No. 3 data, first trial.

Resistivity Data Form

V.E.S. No. 3 2nd trial

Operator: Hernandez - Smith

A B Direction:

Notes:

Location: CHRA

AB/2	MN	K	I	ΔV Scale	ΔV Reading	ρ
10	2	155.5	17.5	1.02	74.7	677.04
10	5	58.9	6.0	1.02	47	470.2
15	2	351.9				
15	5	137.4	19.5	1.02	65	467.15
20	5	247.4	7.0	1.02	10	360.5
30	5	561.5	6.5	0.1	38	328.3
40	5	1001.4	8.5	0.1	19	223.8
40	20	235.6	9.0	0.1	62	171.8
50	5	1566.9				
50	20	377.0	10.5	0.1	15	147.4
70	20	754.0	12.0	0.1	34	213.6
100	20	1555.1	10.5	0.1	25	370.3
100	80	329.9	10.5	1.02	10	320.5
150	20	3518.6				
150	80	820.7	9.0	0.1	58	528.9
200	20	6267.5				
200	80	1508.6	11.5	0.1	64	839.2
300	20	14121.5				
300	80	3471.5	18.0	0.1	74	1427.17
400	20	25117.9	18.5	0.1	55	7893.4
400	80	6220.4	18.5	0.1	46	1635.0
400	200	2356.2	18.5	1.02	36	4441.3
500	20	39254.2	8.0	0.1	12.5	6133.14
500	80	9754.6	8.0	0.1	24.0	2925.3
500	200	3770.0				
650	80	16528.7	15.5	1.02	41	44595.5
650	200	6479.5	15.5	1.02	79.6	33275.4
800	80	2507.0	28.5	1.02	24.5	21441.2
800	200	989.6	28.5	1.02	41.5	16458.6

Table 1b. VES No. 3 data, second trial.

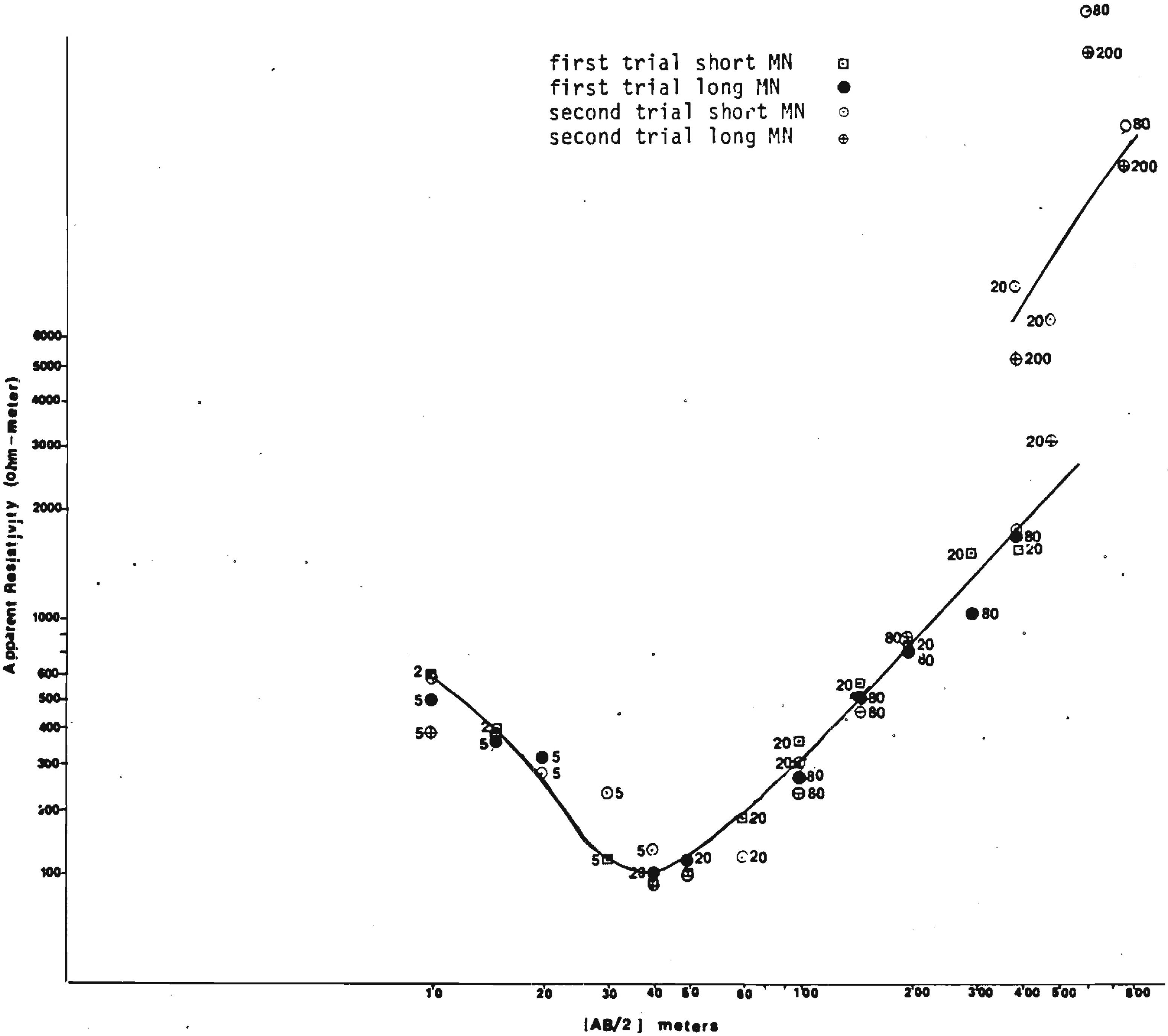


Figure 2. Resistivity curve for VES No. 3.

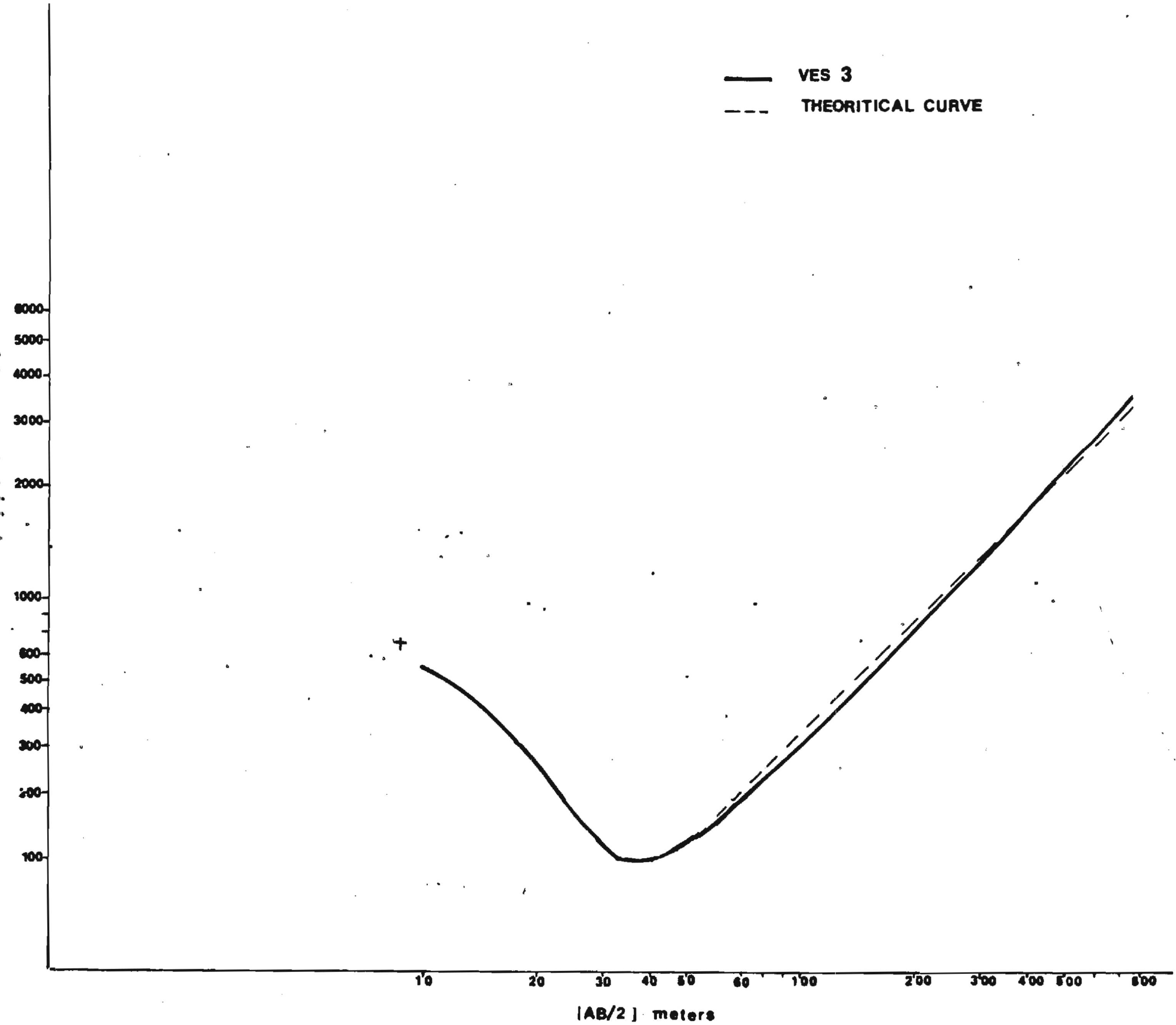


Figure 3. Shows the fit of the resistivity curve of VES No. 3 to theoretical curve with $\rho_2 = 0.1\ \rho_1$, $\rho_3 = \infty$, $h_2 = 2h_1$.

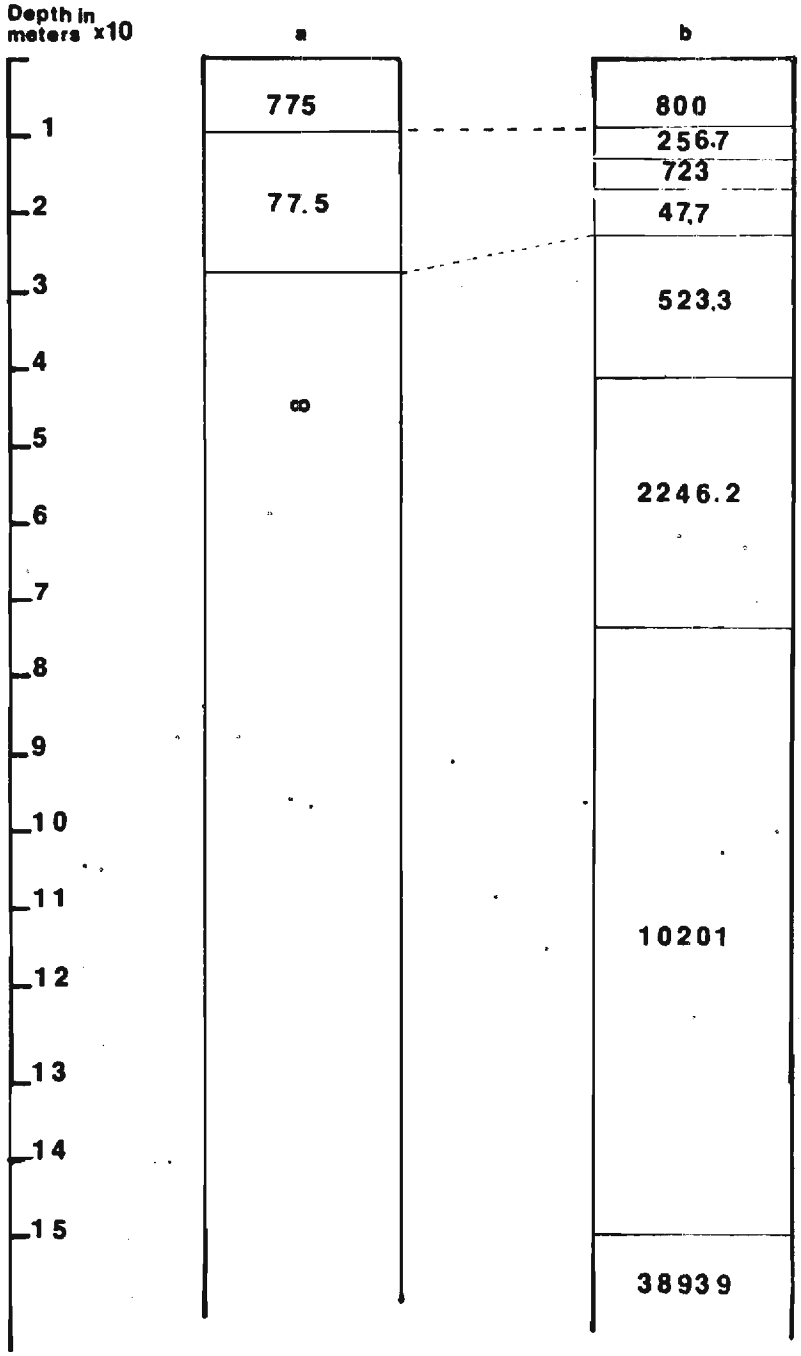


Figure 4. Shows the interpreted resistivity layering for VES No. 3
a) manual interpretation
b) computer aided interpretation

half space (see Figure 4). The computer aided interpretation tends to divide the conductive layer into three layers (Figure 4). This division of the single low-resistivity layer (77.5 ohm-m) of the resistivity found by manual interpretation into three layers is inherent in the automatic interpretation, since the iterative inversion is initiated with n layers where n is the number of digitized points. The high-resistivity half-space interpreted by curbe fitting is likewise divided into layers with increasing resistivity (see Figure 4) by the computer interpretation.

VES No. 4

Vertical electrical sounding number 4 was performed 800 meters northwest of VES No. 3 along the same dirt road. Also as in VES No. 3, the data show scatter (Figure 5). The apparent resistivity data ware interpreted on the basis of the fit of the data to a theoretical curve (Figure 6). As in the case of VES No. 3, the interpretation of the curve is based on the data points obtained with shorter MN spacing for shorter current electrode spacings, and for the longer current electrode the data obtained with the longer MN was chosen for the interpretation. Also, as was observed in VES No. 3, the resistivity tends to increase sharply (at an angle greater than 45°) for (AB/2) distances longer than 400 meters.

In the manual interpretation of VES No. 4 we chose a three layer case (Figure 6) with an eight meter thick resistive surface layer (1300 ohm-m) over a lower resisitivity (260 ohm-m) 24 meter thick layer over a highly resistive half space (Figure 7). The computer aided interpretation reveals a resistive surface layer (1018 ohm-m) nine meters thick over a lower resistivity (470 ohm-m) layer 21 meters thick. However, the highly resistive half space deduced by manual interpretation is divided into a 3294 ohm-meter resistive layer 26 meters thick over a slightly lower resistivity layer (2860 ohm-m) 126 meters thick over two layers with increasing resistivity (see Figure 7) of 7111 ohm-m and 24610 ohm-m.

Horizontal Electrical Profiles

Two horizontal profiles were conducted in the Clark Hill area. These horizontal profiles were conducted with a fixed current electrode spacing of 800 meters. The purpose of the horizontal profile is to investigate the lateral inhomogeneties in the subsurface.

Horizontal profile HP-1 was conducted along the dirt road south of the epicenter region. The data points for this profile are given in Table 3. Horizontal profile HP-2 was conducted across the epicenter area (through the woods) (see Figure 1) and the resistivity data are given in Table 4. HP-2 has not been completed. In the future we plan to continue this profile northward to the location indicated by VES No. 5 (Figure 1).

Preliminary Interpretation

The vertical electric sounding resistivity curves are grouped in one diagram (Figure 8) to show the general characteristic of the resisitivity layering in the area. As may be observed from Figure 8 the characteristic layering is a three layer case with a resistive surface layer overlying a

Resistivity Data Form

V.E.S. No. 4

Operator: Hernandez and Smith

A B Direction:

Notes:

Location:

AB/2	MN	K	I	ΔV Scale	ΔV Reading	ρ
10	2	155.5	8.7	1.0	57	1636.34
10	5	58.9	4.7	1.0	102	590.35
15	2	351.9	[illegible]	[illegible]	[illegible]	4825.2
15	5	137.4	14.5	1.0	[illegible]	674.5
20	5	247.4	2[illegible]	1.0	[illegible]	636.0
30	5	561.6	30.1	1.0	20	485.0
40	5	1001.4		1.0	33	660.9
40	20	235.6	12.2	1.0	35	675.9
50	5	1566.9	50.3	1.0	31	965.7
50	20	377.0	13.2	1.0	29	828.26
70	20	754.0	52.7	1.0	50	715.9
100	20	1555.1	42.9	1.0	43	1558.7
100	80	329.9	10.5	1.0	43	1351.0
150	20	3518.6	54.0	1.0	28	1824.5
150	80	820.7	14.2	1.0	29	1676.1
200	20	6267.5	71.8		14	1222.7
200	80	1508.6	38.0	1.0	48	1904.8
300	20	14121.5	741.5	[illegible]	16	3118.5
300	80	3471.5	73.5	1.0	45	[illegible]
400	20	25117.0	[illegible]	1.0	5.0	6731.1
400	80	6220.4	82.5	1.0	15	[illegible]
400	200	2356.2				
500	20	39254.2	105.1	1.0	9.9	3077.0
500	80	9754.6	[illegible]	1.0	36	3299.36
500	200	3770.0				
650	80	16528.7	78	1.0	12	6784.62
650	20	76575.8	74	[illegible]	[illegible]	[illegible]
800	80	2507.0	78.2	[illegible]	[illegible]	[illegible]
800	20	25117	29.2	[illegible]	[illegible]	1253.7

Table 2. Resistivity data for VES No. 4.

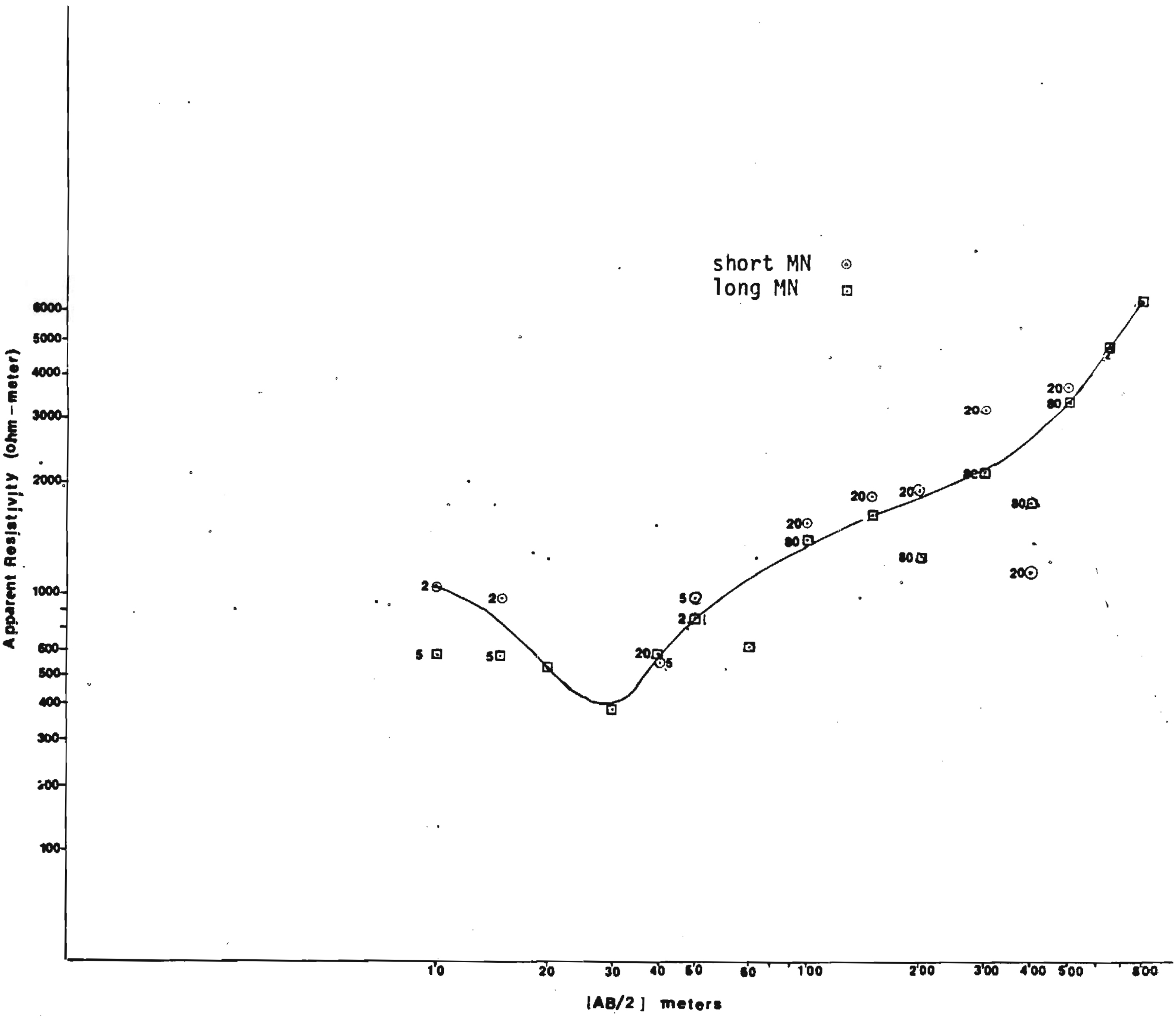


Figure 5. Resistivity curve for VES No. 4.

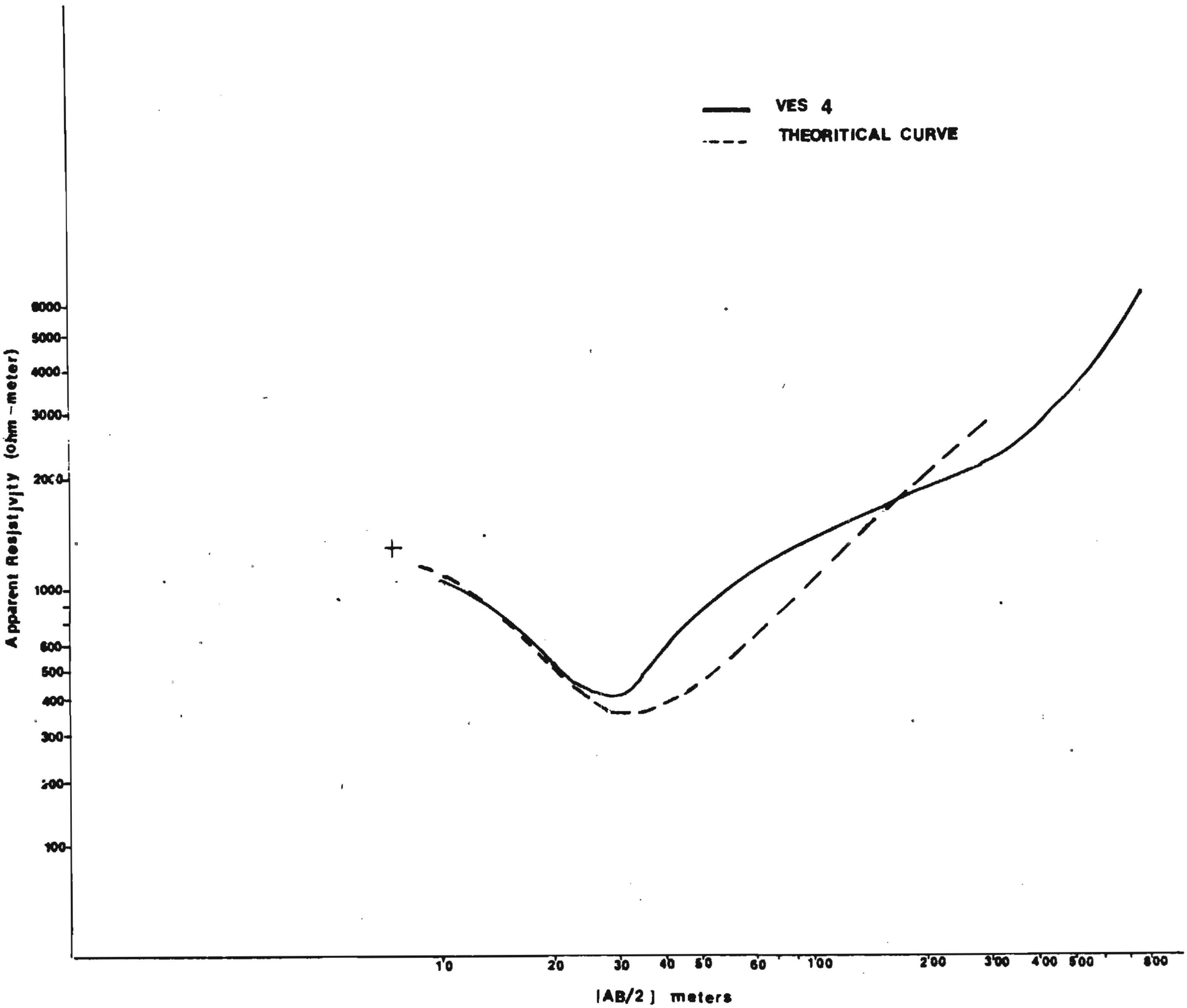


Figure 6. Shows the fit of the resistivity curves of VES No. 4, with the theoretical curve with $\rho_2 = .2\rho_1$, $\rho_3 = \infty$, $h_2 = 3h_1$.

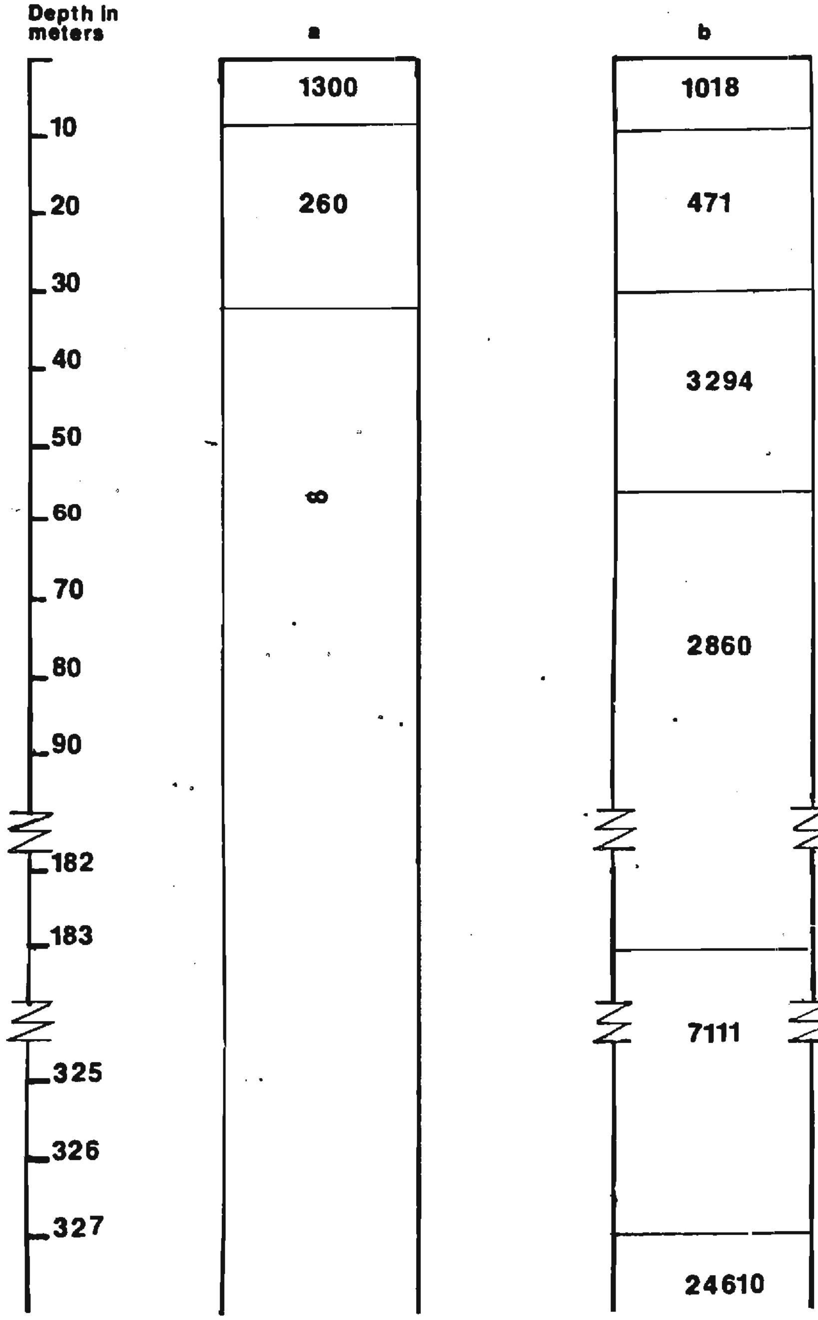


Figure 7. Shows the interpreted resistivity layering for VES No. 4
a) manual interpretation
b) computer aided interpretation

No.	ΔV_1	I_1	ΔV_1 scale	ΔV_2	I_2	ΔV_2 scale	ρ_1	ρ_2	ρ_a
1	52.0	34.8	1.0	41	33.5	1.0	3520	3305	3412
2	36	32.9	1.0	26.0	26.0	1.0	2578.2	2401.5	2489
3	88	71.1	1.0	44	70.5	1.0	2916.3	3141	3028
4	38	47.8	1.0	39	49.6	1.0	1873.2	1852.6	1862
5	30	43.2	1.0	31	42.0	1.0	1636.25	1714.6	1675

Table 3. Resistivity data for horizontal profile HP1.

No.	ΔV_1	I_1	ΔV scale	ΔV_2	I_2	ΔV scale	ρ_1	ρ_2	ρ_a
1	87	48.0	1.0	97	54.8	1.0	4200	4170	4185
2	36	23	1.0	34	22	1.0	3687.9	3641.4	3664.4
3	23	17.4	1.0	21	17.0	1.0	3114.52	2916.6	3015.2
4	18	9.2	1.0	19	9.1	1.0	4609.9	4919.5	4764.7
5	10	4.1	1.0	12	4.8	1.0	5746.8	5896.6	5818.6

Table 4. Resistivity data for horizontal profile HP2.

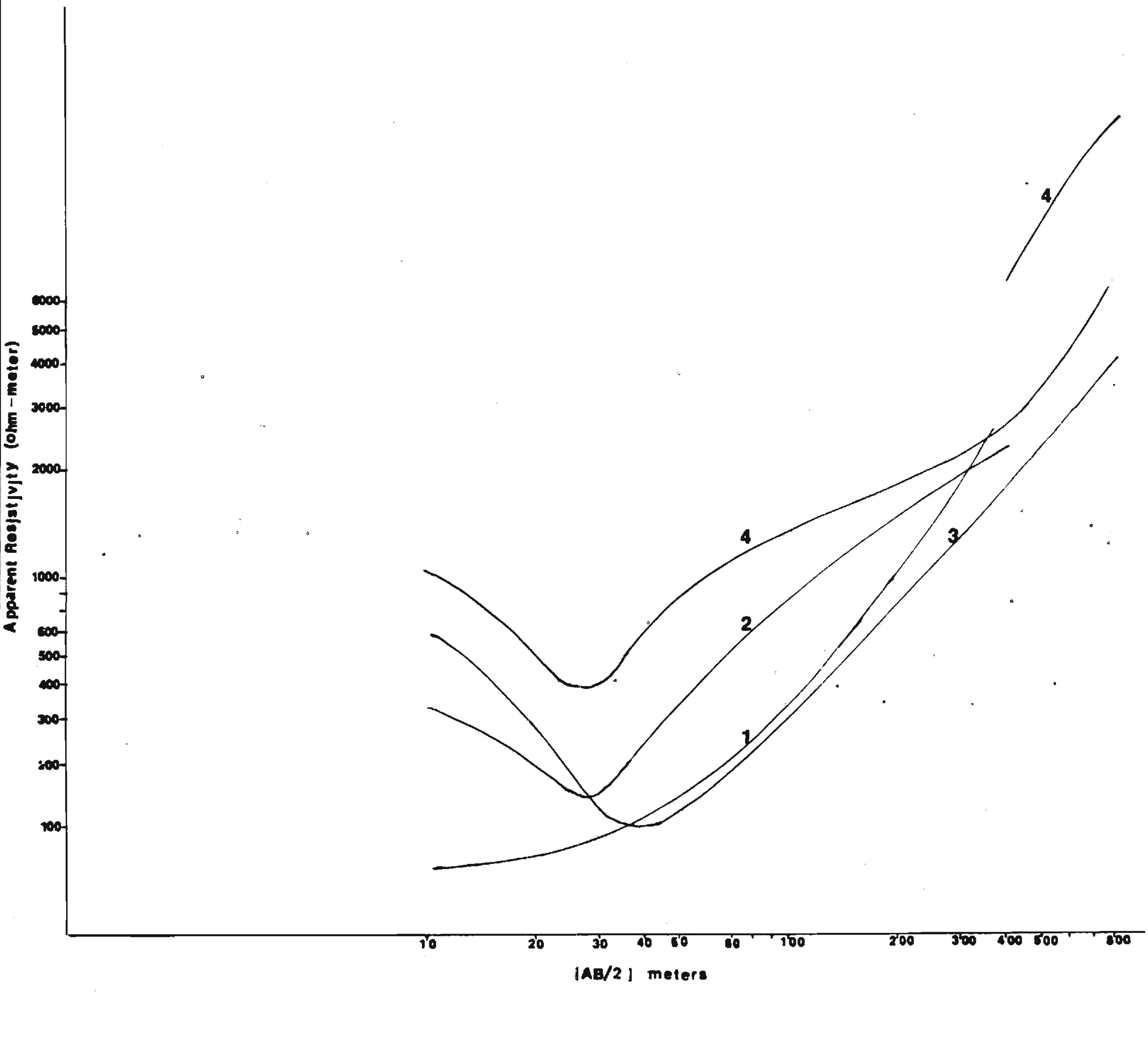


Figure 8. Composite plat of the resistivity curves for VES No. 1, VES No. 2, VES No. 3 and VES No. 4.

lower resistivity layer over a half space. An exception to this layering is observed for VES No. 1 where the surface resistive layer is absent.

Figure 9 shows a block diagram of the interpreted resistivity layers, which are projected with respect to the topographic elevation of each VES center. The normal lake level for the Clark Hill reservoir is shown for comparison. Also shown in Figure 9 is the interpolated block diagram of the intermediate layer.

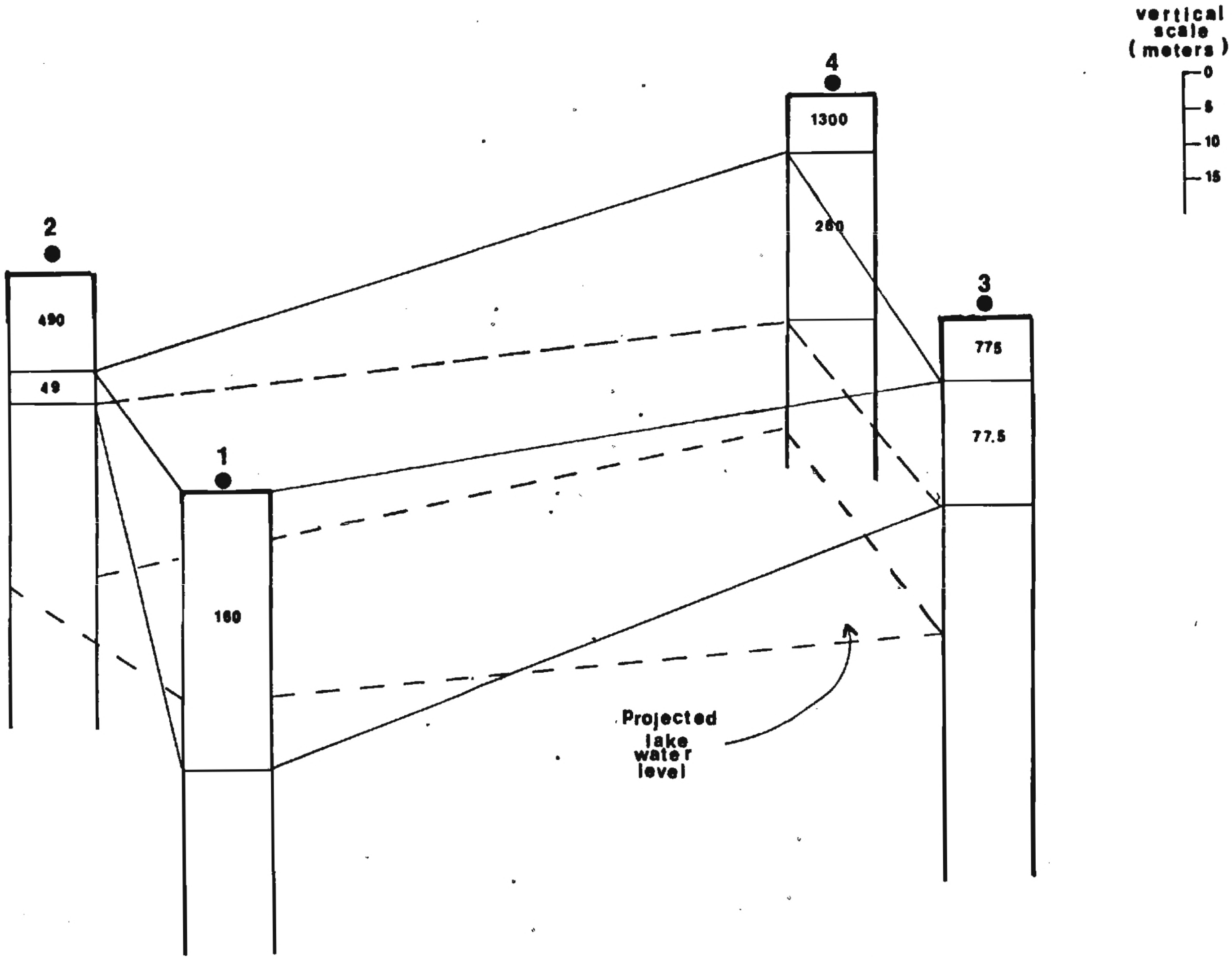


Figure 9. Block diagram, showing the interpreted resistivity layers, with the lower resistivity middle layer cross correlated to show the extension of the layer. Also shown is the projected normal lake water level.

Appendix A

Computer aided interpretation for

VES No. 1 and VES No. 2

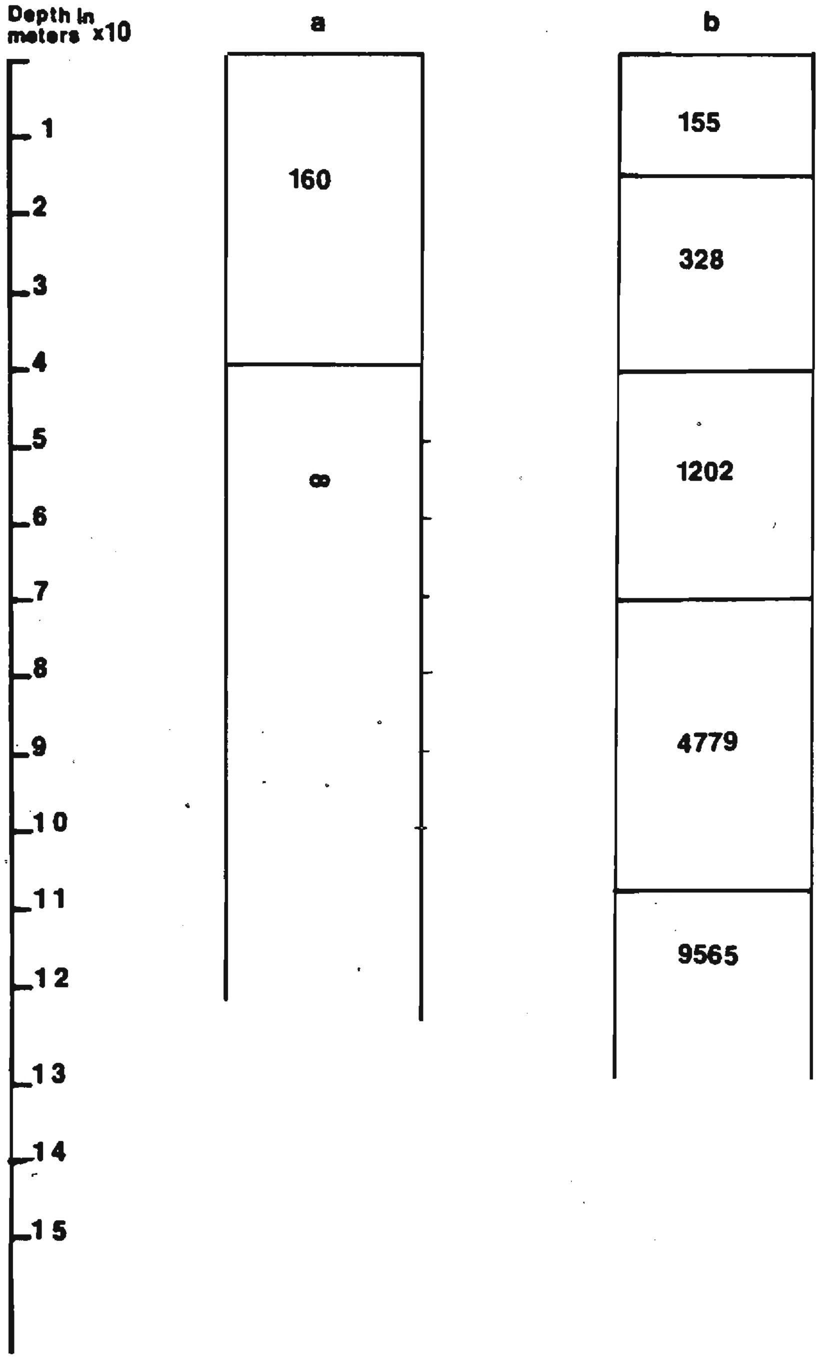


Figure 10. Shows the interpreted resistivity layers for VES No. 1.
a) manual interpretation
b) computer aided interpretation

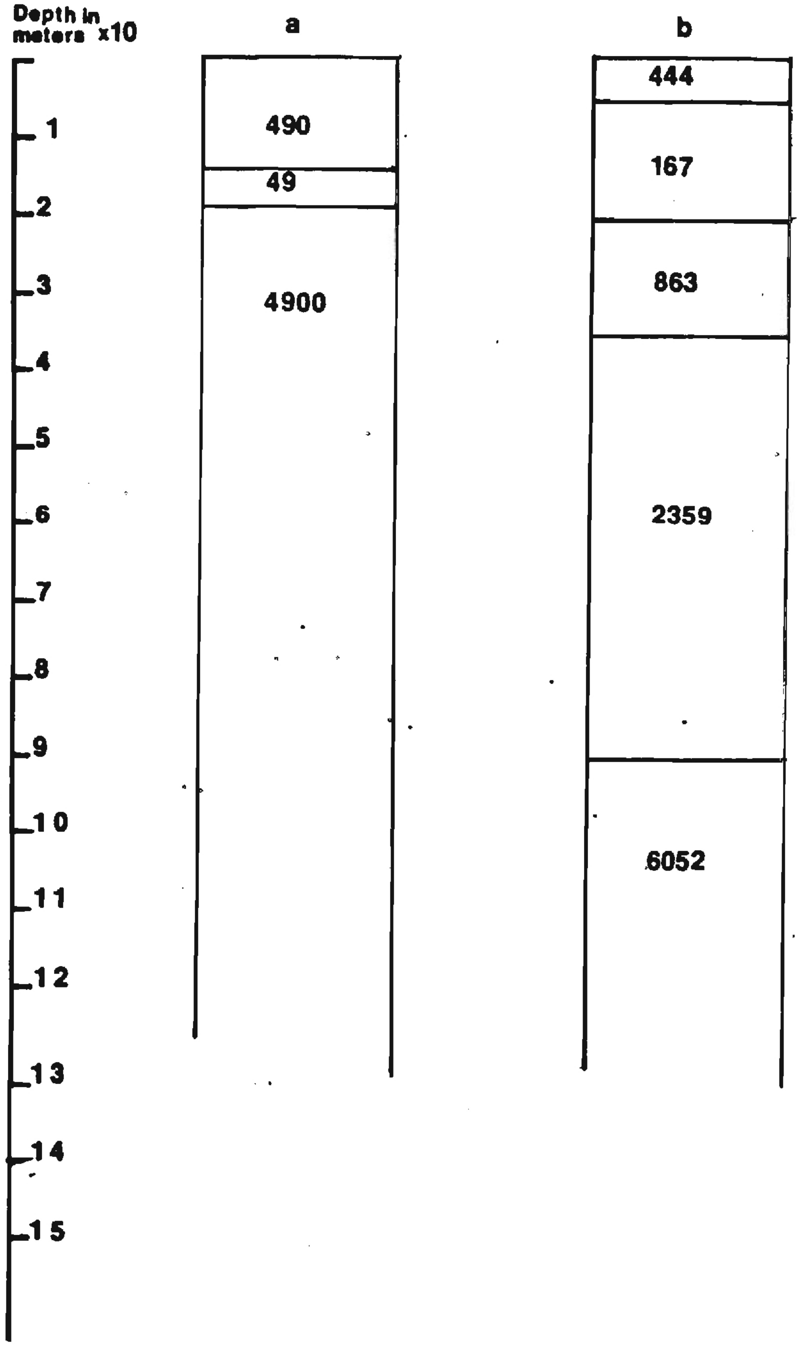


Figure 11. Shows the interpreted resistivity layers for VES No. 2.
a) manual interpretation
b) computer aided interpretation

NUREG-0019
G35-633 (662)

A GEOPHYSICAL INVESTIGATION OF THE SEISMICITY OF THE CLARK HILL RESERVOIR VICINITY

Quarterly Progress Report No. 15

December 1, 1978 to February 28, 1979

Leland Timothy Long
School of Geophysical Sciences
Georgia Institute of Technology
Atlanta, Georgia 30332

Report Due Date February 28, 1979
Submitted March, 1980

PREPARED FOR THE U. S. NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR REGULATORY RESEARCH
UNDER CONTRACT NRC-04-77-210

A Geophysical Investigation of the Seismicity of the
Clark Hill Reservoir Vicinity
Quarterly Progress Report No. 15

Abstract

Seismic monitoring continued at stations CH5, CH6, and ETG. A new approach to surface wave analysis was formulated during the period with the objective of being able to obtain information on near-surface shear wave velocity with short-period instruments. In addition, a study of teleseismic traveltime residuals was formulated and initiated with the objective of obtaining information on upper mantle and crustal structures.

Scope of Investigation

To determine the relation between geology and seismicity and to determine the tectonic environment that is responsible for earthquakes in the Clark Hill Reservoir vicinity by continuing to monitor seismic activity rates versus water level in the Clark Hill Reservoir area and to locate seismic events. During periods of increased activity, portable instruments will be used to compute locations, focal mechanisms and spectral signature. Stations CH5 and CH6 will be maintained in continuous operation. Three RF stations will be operated in the area of the earthquake of August 2, 1974 (Mag 4.3) to provide locations and origin times for the continuing aftershocks. Data from these stations will be coordinated with proposed U.S. Corps of Engineers net in the Richard B. Russell reservoir area. One station will be maintained (ETG) to monitor the activity near Lake Sinclair in conjunction with continued operation of the Wallace Dam net WDG (expanded to 3-component) GBG, REG and one new station to improve location of events in the Lake Sinclair area. A suite of four portable smoked paper recording seismographs will be used intermittently in areas of special interest. Areas of special interest will be surveyed using the direct current electrical resistivity sounding to typical depths of the earthquakes (0.5 to 1.0 km) to determine penetration by ground water. Areas in the yet unfilled Richard B. Russell reservoir area (directly north of CHRA) will be similarly surveyed.

Results of Investigation During Quarter

Recording Summary: Seismic monitoring continued with only one two week interruption in January at CH5 (double branches in the southern part of the CHRA). CH6 was not operating for 2 weeks in January and 3 weeks in February. The RF station EP1 did not operate during the period because of required modification and repair. A log of the seismic activity was maintained for the aftershock zone of the August 2, 1974 earthquake. Figure 1 shows the number of events recorded at station CH6 or its equivalent versus water level during the period of December through February. The only detected activity was a small swarm of 11 events in December. This swarm occurred when the reservoir water was at a minimum.

Station ETG in the Wallace Dam area operated during the entire period. Figure 2 shows the events detected by the Wallace Dam net. All of our readings of local and regional events detected during the period at stations operated out of Georgia Tech have been made available for publication in the southeast United States seismic network bulletin.

Seismic Velocity Determination: In investigating ways in which seismic velocity could be determined for structures in the area of the CHRA, the use of surface waves was suggested. Because we were interested in rocks in the depth range of 0.1 to 10 km, surface waves of period 3 sec to 0.1 sec would be required. Such surface waves of both Love and Rayleigh type are commonly observed in the Piedmont and ususally show dispersion. However, these wave trains are seldom sufficiently dispersed to allow application of the traditional filtering techniques. However, phase velocity analysis from a tripartite array could be used if individual phases could be identified. But, in our existing data, many of these phases were obscured by higher frequency scattered phases. Group velocity analysis normally is not applied to a tripartite array and our existing data could not be analyzed by traditional filter techniques. It was clear that some other type of analysis method was necessary. That method would have to be able to identify low-frequency surface waves emersed in higher frequency noise and be applicable to short segments of the signal in order to obtain a time resolution necessary for determining meaningful shear wave velocities. Maximum Entropy Spectral Analysis (MESA) satisfies these conditions. Sometime previously I had suggested that Wasim Munasfi consider the use of MESA in surface wave analysis. As a result of his preliminary consideration we decided to develop an analysis procedure by preparing appropriate computer programs and obtain field data in the CHRA for application of the technique. During this period the programs were initially developed and tested on noise and synthetic waves to evaluate resolution capability. Choice of appropriate filter length was also evaluated using the synthetic waves with noise. Three attempts to obtain data were completed during the period but instrument failure and insufficient trace resolution prevented obtaining usable data. Nevertheless, the tests on theoretical data were encouraging and this approach to the determination of crustal structure will be continued.

A Study of Deep Crustal Structure: Also, during this period another program to measure velocity structure was formalized as a masters thesis by Bill Volz. The objective of this thesis was to use teleseismic arrival time perturbations and the inversion method of Aki to obtain velocity perturbations in the crust and upper mantle of the southeastern United States. During this period, an initial data set was obtained from the Georgia Tech stations including CH5 and CH6. An initial computer program was written and test on models were begun. Also, a copy of Aki's computer program was obtained but was not used because it did not lend itself to the station distribution in the southeastern United States.

Spectral Data: During this period the studies of seismic spectra were taken over by a USGS funded project to evaluate spectral shape as an discriminant for reservoir induced seismic activity.

Resistivity: Seasonal weather prevented to obtaining of any resistivity data during this period.

Progress During Quarter: The project progressed at a reasonable rate during the quarter.

Efforts Expended During Quarter: The principle investigator expended an average of 15 percent time on the project during the quarter. One Electronics Technician expended about 25 percent time during the quarter. One Graduate student worked at about one third time during the quarter.

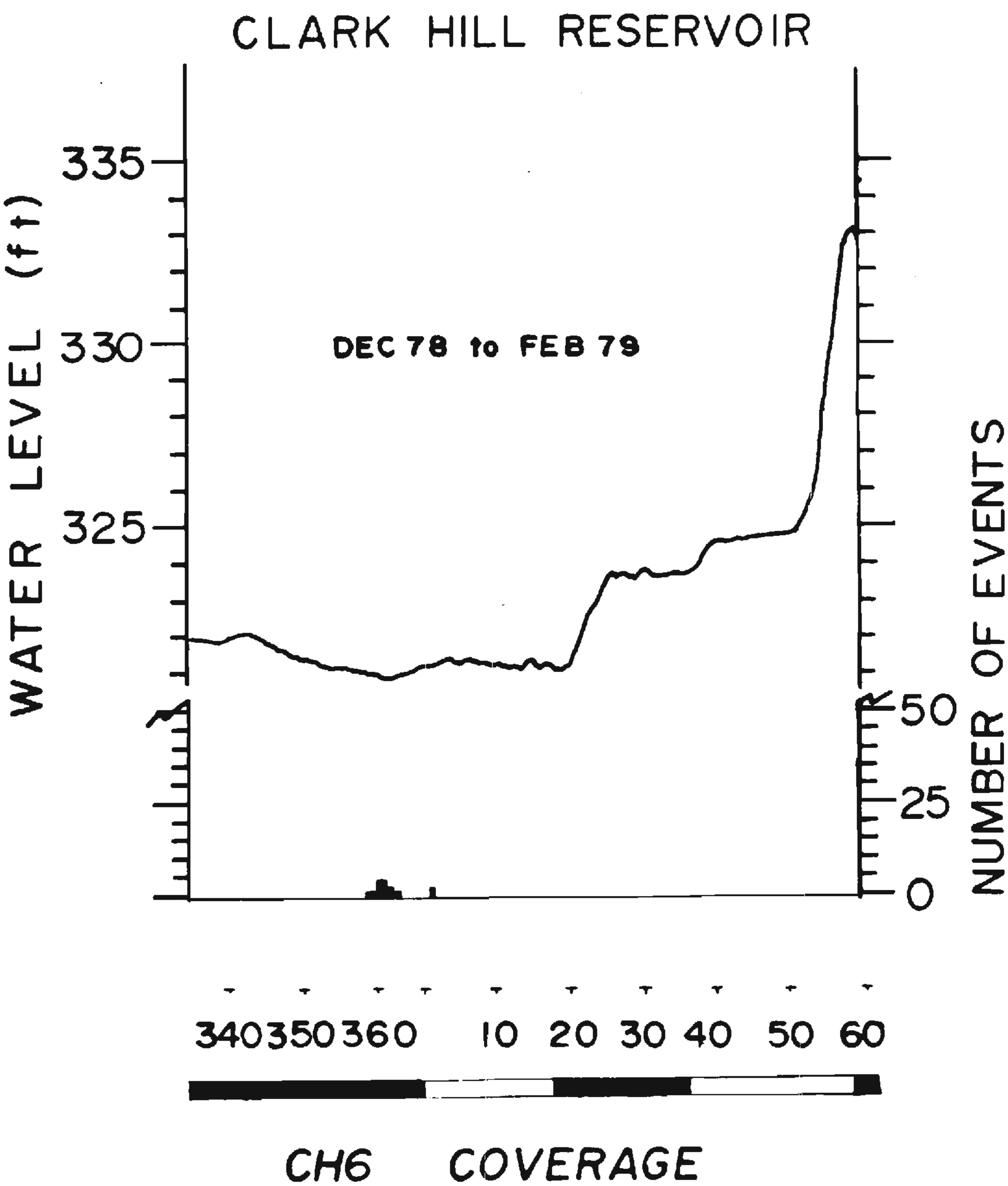


Figure 1. Seismic activity versus water level.

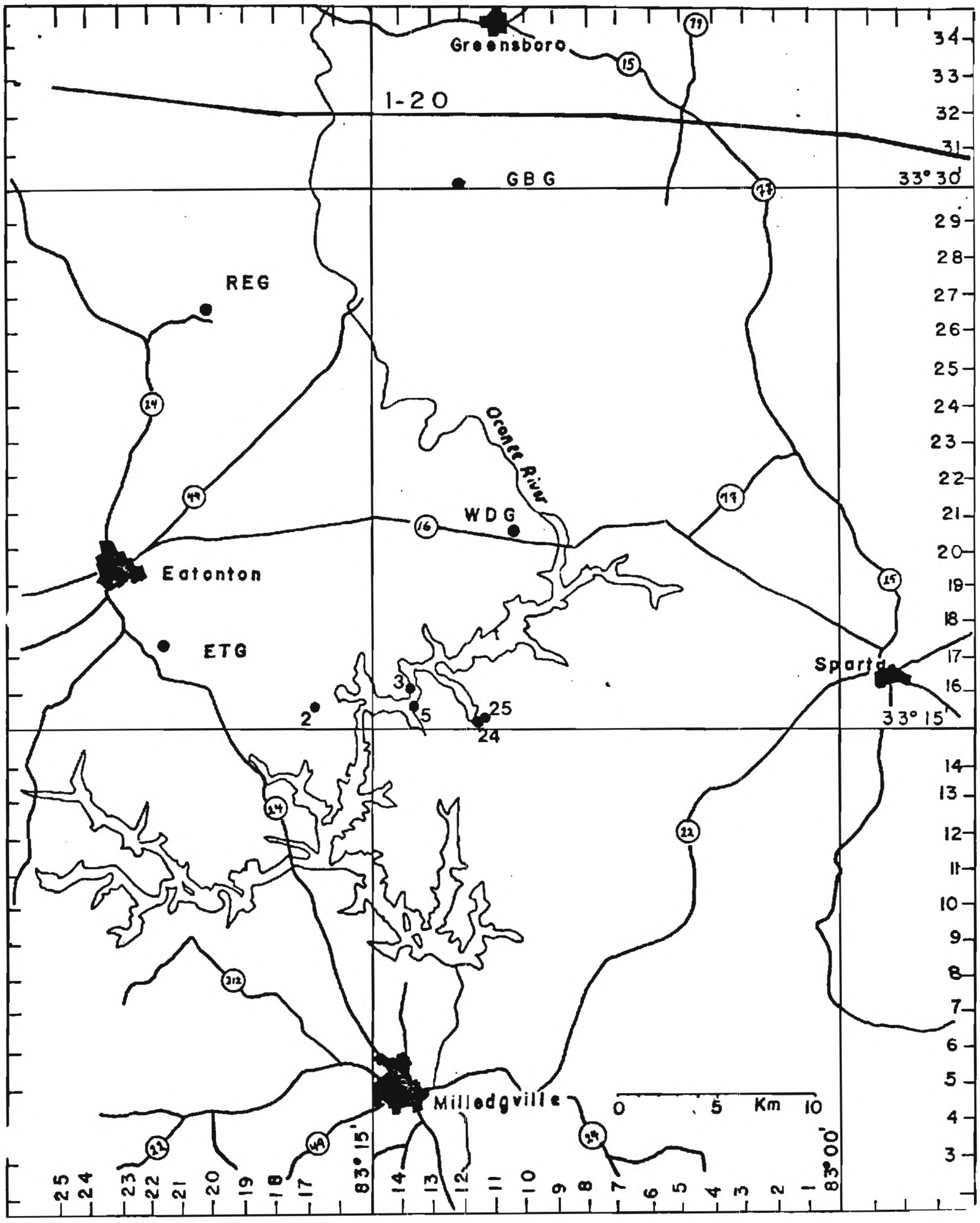


Figure 2. Earthquakes located in the Lake Sinclair region with the help of station ETG. Dots indicate earthquake location.

NUREG-0020
G35-662

A GEOPHYSICAL INVESTIGATION OF THE SEISMICITY OF THE CLARK HILL RESERVOIR VICINITY

Quarterly Progress Report No. 16

March 1, 1979 to May 31, 1979

Leland T. Long
School of Geophysical Sciences
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Report Due Date May 31, 1979
Submitted February 1980

PREPARED FOR THE U. S. NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR REGULATORY RESEARCH
UNDER CONTRACT NRC-04-77-210

A Geophysical Investigation of the Seismicity of the CLark Hill Reservoir Vicinity

Quarterly Progress Report No. 16

Abstract

Seismic monitoring continued at stations CH5, CH6 and ETG. Our Maximum Entropy surface wave analysis method was tested on long period seismograms. In our application of the Aki type inversion of teleseisms a traveltime the inversion process was reevaluated and a new inversion precedure was developed. A technique and procedure for using three-component seismograms and shear wave polarization analysis for focal mechanism solutions was formulated.

Scope of Investigation

To determine the relation between geology and seismicity and to determine the tectonic environment that is responsible for earthquakes in the Clark Hill Reservoir vicinity by continuing to monitor seismic activity rates versus water level in the Clark Hill Reservoir area and to locate seismic events. During periods of increased activity, portable instruments will be used to compute locations, focal mechanisms and spectral signature. Stations CH5 and CH6 will be maintained in continuous operation. Three RF stations will be operated in the area of the earthquake of August 2, 1974 (Mag 4.3) to provide locations and origin times for the continuing aftershocks. Data from these stations will be coordinated with proposed U.S. Corps of Eigineers net in the Richard B. Russell reservoir area. One station will be maintained (ETG) to monitor the activity near Lake Sinclair in conjunction with continued operation of the Wallace Dam net WDG (expanded to 3-component) GBG, REG and one new station to improve location of events in the Lake Sinclair area. A suite of four portable smoked paper recording seismographs will be used intermittently in areas of special interest. Areas of special interest will be surveyed using the direct current electrical resistivity sounding to typical depths of the earthquakes (0.5 to 1.0 km) to determine penetration by ground water. Areas in the yet unfilled Richard B. Russell reservoir area (directly north of CHRA) will be similarly surveyed.

Results of Investigation During Quarter

Recording Summary: Seismic monitoring continued without major interruption at CH5 (double branches in the southern part of the reservoir) and at CH6 (near Goshen in the northern part of the reservoir). Station EP1 operated in the epicenter area as a three component system during March and through April 12, 1979. A log of the seismic activity was maintained for the aftershock zone of the August 2, 1974 earthquake. Figure 1 shows the number of events recorded at CH6 (or its equivalent) versus water level. A swarm of events occurred during late March and early April. The swarm consisted of a sequence of short swarms separated by a period of 6 to 7 days. These swarms began 30 days after an increase of 10 ft. in reservoir water level during February. Prior to the swarm the water level had dropped back down 5 feet. The swarm occurred immediately after a water level increase of two feet. The causal relation between water level changes and seismicity is not clear. We believe these events may best be associated with the February water level increase of more than 10 ft.

Station ETG has been recording in the Lake Sincalir area and operated without any major interruption during this period. Events located by ETG and the Wallace Dam net funded by Georgia Power Company are shown in Figure 2. Only one event was detected in the Lake Sinclair area during the period.

All of the local and regional data recorded at stations operated out of Georgia Institute of Technology have been logged and regional earthquake data have been made available for publication in the southeast United States Seismic Networks Bulletin.

<u>Seismic Surface Wave Velocity Determination</u>: During this period the programs for Maximum Entropy Spectral Analysis of surface waves were further developed and tested. In particular, long period surface wave data recorded on WWSSN stations were used to test the analysis procedure to allow comparisons with the traditional multiple filter techniques. Window length and spacing were examined to allow optimum resolution with reasonable computer time.

<u>A Study of Deep Crustal Structure</u>: In the application of Aki's method to teleseismic arrivals in the southeast United States, difficulties were encountered in the inversion process. In Aki's original and in most subsequent work these difficulties are overcome by use of damped least squares. However, we felt that damped least squares compromises the data too much and have consequently developed a method using constraint equations to remove singularities. We also discovered that the averaging process for each event will bias the results if different sets of stations are available for different events (the usual case). Hence, in the least squares reduction we included a solution for the mean arrival time for each event. During the period, techniques to identify erroneous data were developed and new data were obtained. A talk on the preliminary results was presented at the Seismological Society of American meeting by Bill Volz. An abstract is attached.

<u>Source Mechanism using S-wave Polarization</u>: During this period a program to incorporate S-wave polarization data in focal mechanism determinaltion was formulated. The study will become a masters thesis project for Gordon Smith. The objective is to allow use of station EP1 3-component data and a few other single component stations to determine focal mechanisms better than possible with only P-wave first motions. The project will require three major tasks. The first will be to modify the focal mechanism computer program developed by Guinn and Long to include S-wave polarizations. The second will be to develope analysis procedures to account for the free surface effect (which can be large)

and to allow correct measurement of the polarizations angle. The third will be to obtain data to test the method. Hopefully station EP1 will record sufficient data for this analysis.

Spectral Analysis Studies: The study of seismic spectral fall off rates and their dependence on areas susceptible to induced seismic activity continued under USGS sponsorship. A literature survey for data was unrewarding, but the few examples found seem to confirm the correlation of cubic decay with reservoir induced activity. In a detailed analysis of the magnitude versus distance domain in which spectra could be computed reliably above the corner frequency, we found that WWSSN data would be limited to magnitude 3±.3 events at 15±5 km recorded at gains less than 50 K. Typical telemetry systems provide a wider range of possible data ($M = 2\pm0.5$, 5 to 30 km, gain $\leq$ 200 K). Data from the CHRA and ETG in the Wallace Dam area were searched for events appropriate for possible spectral analysis.

Resistivity Studies: Three attempts were made during the period to obtain electrical Schlumberger depth soundings in the aftershock zone of the August 2, 1974 earthquake in the CHRA. On March 19-20 depth probe number 3 was completed. On April 20 and May 17 depth probe number 4 was performed. These two depth soundings were centered 400 meters apart along a North-South trending line. Number 3 was centered over the Westward extension (about 1 km) of the aftershock zone and within a half kilometer of a few events previously located.

Thermal Elastic Stress Analysis: During the period the work of Lee Brown on a thermoelastic model for stress accumulations along a vertical crack with fluid flow was reviewed and presented at the SSA Annual meeting. These qualified results indicate that it is possible to develop thermoelastic stresses exceeding 1.0 bar in 30 days at depths of 0.5 km with a crack width equivalent to 0.06 cm.

Regional Tectonics: The hypothesis of a central Piedmont Rift zone which developed from research on the geological history of the CHRA was given as an invited talk at the Southeastern Section of the Geological Society of America April 26, 1979.

Induced Seismicity: On May 1, 1979 a presentation was given at a workshop on induced seismicity sponsored by the U.S. Geological Survey. The presentation briefly summarized Georgia Tech's work in the CHRA and related work near other reservoirs.

Seismicity: An invited talk on the seismicity of Georgia was presented at the Second Symposium on the Geology of the Southeastern Coastal Plain. This talk was a summary of the earthquake history of Georgia including the CHRA and a discussion of risk in Georgia. The abstract is attached.

Progress During Quarter: The project progressed at a reasonable rate during the quarter.

Efforts Expended During Quarter: The principle investigator expended an average of 20 percent time on the project during the quarter. One electronics technician expended about 10 percent time during the quarter. Graduate students worked at about one-third time during the quarter.

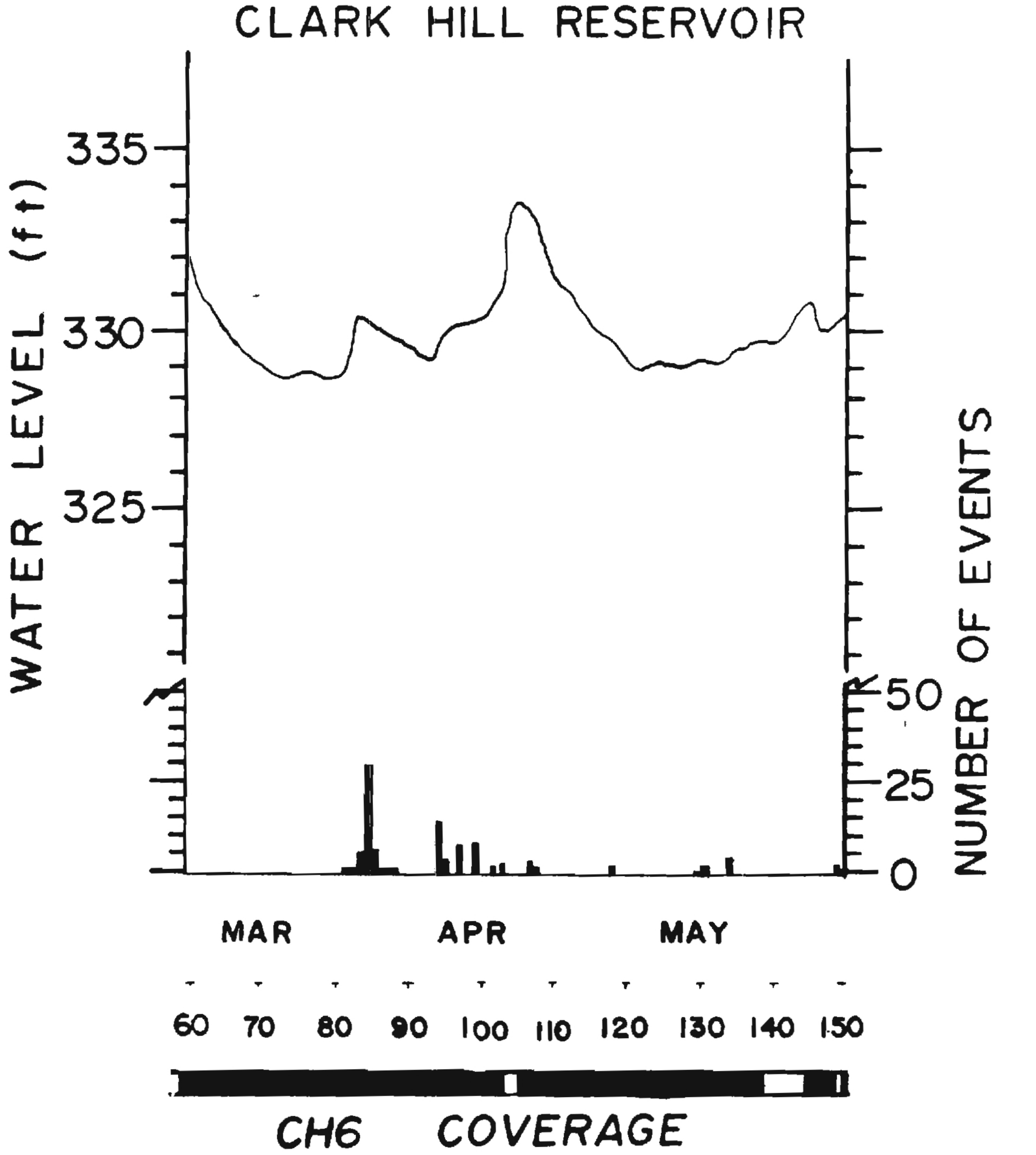

Figure 1. Log of activity versus water level for the Clark Hill Reservoir area.

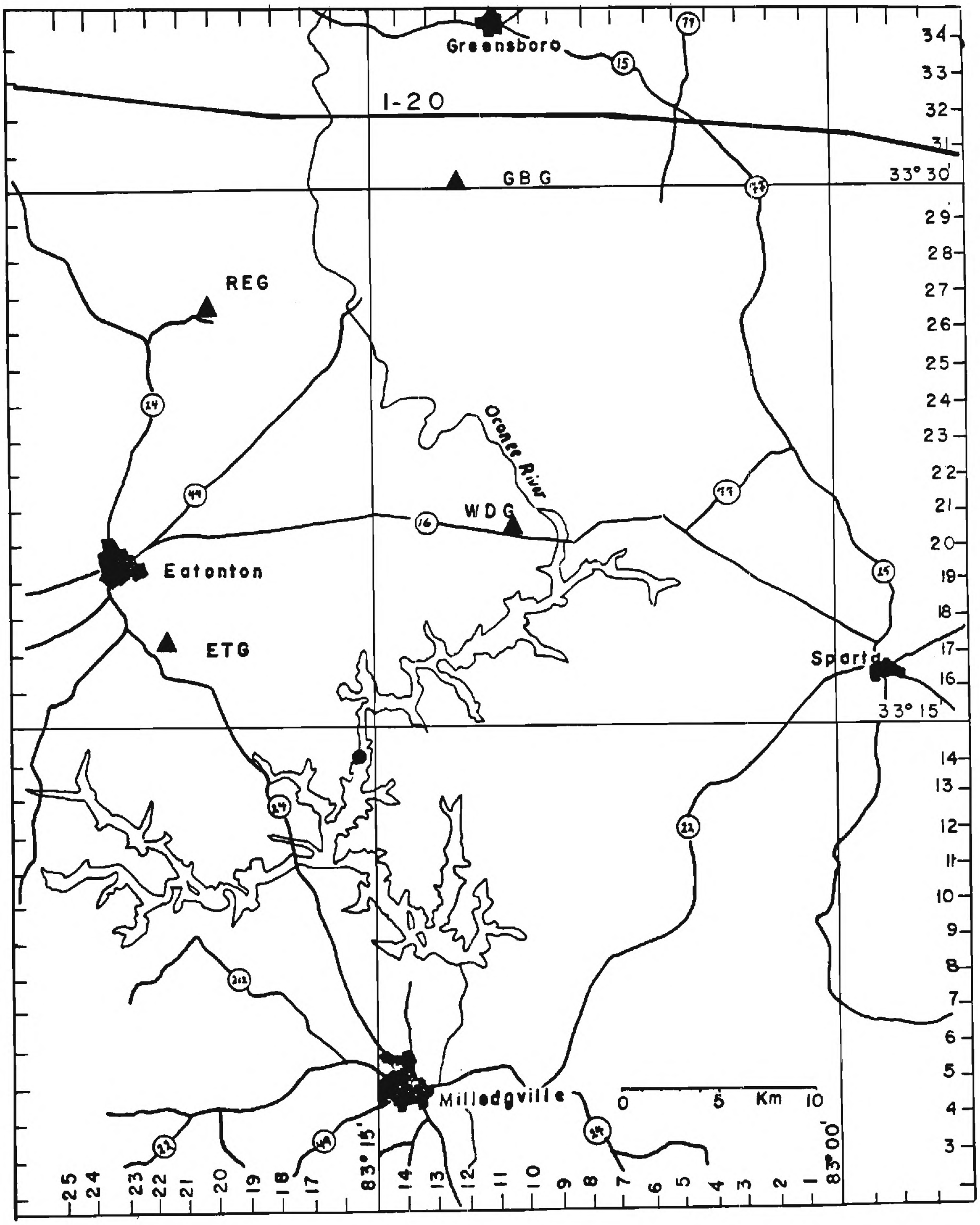

Figure 2. Earthquakes located in the Lake Sinclair region with the help of station ETG. Dots indicate earthquake location.

A THERMOELASTIC MODEL FOR STRESS ACCUMULATIONS ALONG A VERTICAL CRACK WITH FLUID FLOW

LONG, L. T. and BROWN, C. L., School of Geophysical Sciences,
Georgia Institute of Technology, Atlanta, GA 30332

A two-dimensional thermoelastic model shows that thermal stresses may play an important role in the development of stress beneath or near artificial reservoirs. The model studied in detail consisted of a vertical crack with an initial fixed crack width that extends into a semi-infinite medium with the properties of competent basement rock. Fluid, which is colder than the rock, flows down the crack and perturbs the initial temperature field. Stresses are generated in the medium if a non-uniform temperature distribution is established due to the fluid flow. The two-dimensional model shows that with fluid flow and crack width of 0.06 cm, stresses will develop, will migrate down the crack and will increase in magnitude with time. The stress can exceed 1.0 bar in 30 days and 10 bars in 180 days at depths of 0.5 km. The stress is tensional and parallel to the crack wall. With crack widths less than 0.04 cm, only slight near-surface stresses are developed.

THE CAROLINA SLATE BELT MAY BE A CONTINENTAL RIFT

LONG, Leland Timothy, School of Geophysical Sciences
Georgia Institute of Technology, Atlanta, Georgia, 30332

The Carolina Slate Belt and parts of the adjacent Charlotte Belt in Georgia, South Carolina and North Carolina are characterized by positive Free Air and Bouguer gravity anomalies. The northwestern boundary is marked by the Piedmont Gravity Gradient. Density models for this boundary imply shallow, high-density rocks to the southeast and deep (30 to 40 km) low-density rocks to the northwest. Isolated negative Bouguer gravity anomalies southeast of the Slate Belt have geometrical contour patterns similar to those of the Piedmont gravity gradient and imply a similar density model. These similarities suggests that the isolated negative anomalies are derived from fragments of continental crust which may have been separated from a larger continental block by a rift zone. The axis of this proposed rift is the Carolina Slate Belt. Seismic data in Georgia support the rift interpretation by indicating a rift-zone velocity structure with a (6.3 km/sec) discontinuous surface layer which is up to 5 km thick over a low-velocity (6.0 km/sec) crust which extends to depths of at least 30 km. The observed crustal velocities are lower than 6.6 km/sec which would be required for the interpretation of the Slate Belt being underlain by oceanic crust or an island Arc.

TRAVEL TIME INVERSION OF TELESEISMIC P-WAVES IN THE SOUTHEASTERN UNITED STATES

VOLZ, W. R., School of Geophysical Sciences,
Georgia Institute of Technology, Atlanta, GA 30332

Travel time residuals of teleseismic P-waves in Georgia and South Carolina have been interpreted using a method first proposed by Aki, _et al_. (1977). Perturbations in travel times in a three-dimensional block structure are determined from observed travel time anomalies of teleseismic P-waves at the surface by a least squares inversion technique. These travel time perturbations may be interpreted as changes in the thickness of the layering, a lateral change in velocity or a combination of both. The method has been modified by the use of constraint parameters to allow a solution from the limited station distribution of the Southeast United States. Preliminary results confirm a thickening of the crust under the Appalachian Mountains. In addition, low velocities in areas situated under surface exposures of intrusive granites appear to extend into the upper mantle.

SEISMICITY OF GEORGIA

by

Leland Timothy Long

Abstract: The locations of earthquakes which have occurred in Georgia are shown on figure 1. The distribution of earthquakes and seismic risk can be discussed separately for the three regions outlined in figure 1; the Southern Appalachian Seismic zone, the Central Piedmont Seismic Zone and the Coastal Plain. The active part of the Southern Appalachian Seismic zone affects only the northwestern corner of Georgia and consists of scattered events of MM intensity VII or less. One event of MM intensity V or greater should be expected each 5 to 10 years in northwestern Georgia and adjacent areas of Alabama and Tennessee. The Central Piedmont Seismic Zone extends northeast from Milledgeville into South Carolina. The historical seismic record indicates a concentration of events in central Georgia and near the Savannah River. However, events with MM intensities of VII should be expected to occur anywhere within the Central Piedmont Seismic Zone. One intensity V or greater event occurs approximately once each 10 years. Earthquakes in the Coastal Plane of Georgia are more scattered and less numerous than in other areas of Georgia. Of the six events shown in figure 2 only the southern Georgia earthquake near 82.2°W 32.2°N of December 27, 1976 is well documented and its maximum MM intensity was V.

Reports of very local earthquake-like vibrations are occasionally reported along the Georgia Coast, but these are generally attributed to super-sonic aircraft or military tests off shore.

No fault in Georgia has been found to be associated with seismic activity. Large geologic faults and shear zones can be found throughout north Georgia and have been interpreted from geophysical data in the Coastal Plain of South Georgia. These faults are considered inactive today.

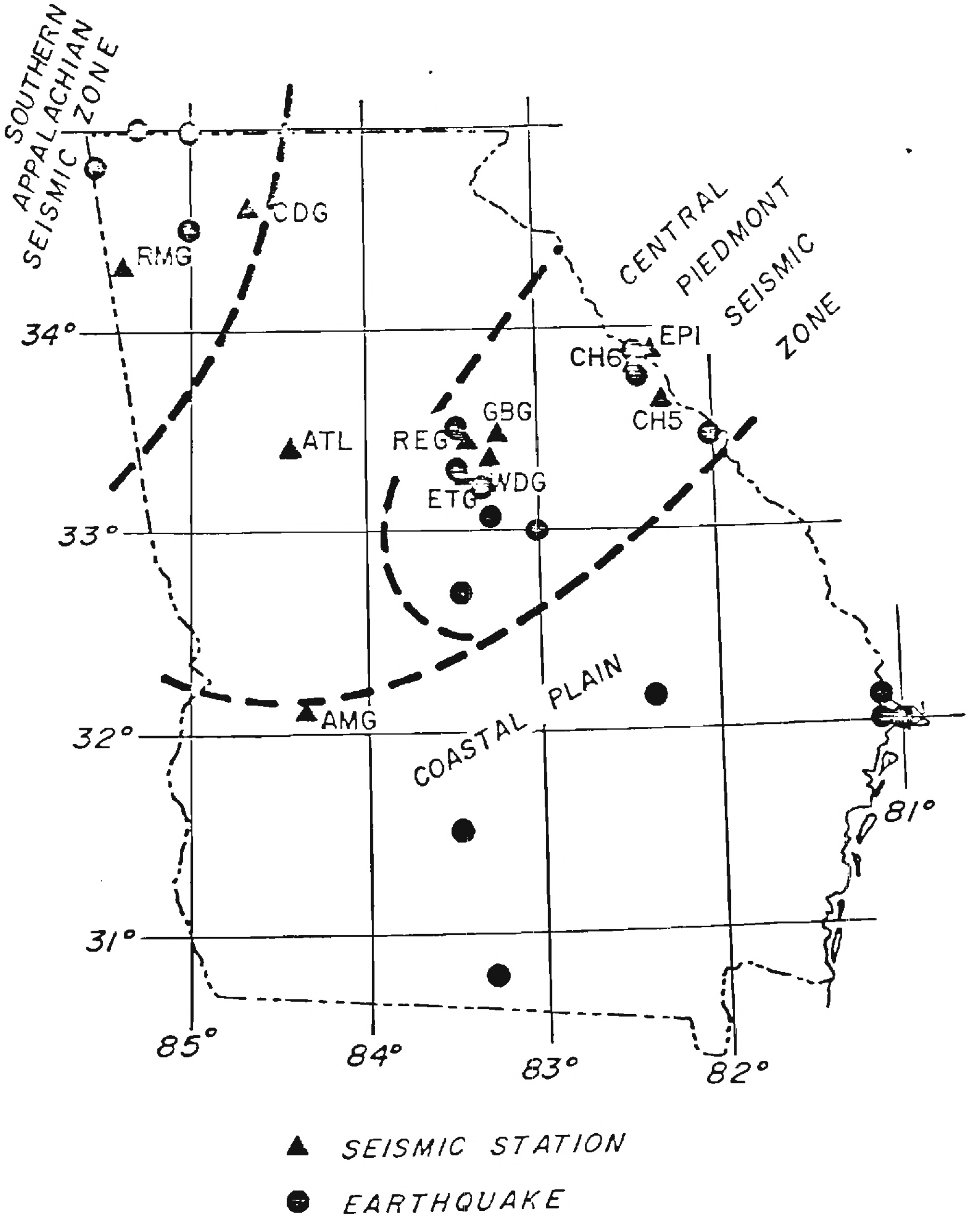

Figure 1. Location map for earthquakes occurring in Georgia and outline of zones of seismic activity in Georgia.

NUREG-0021
G35-662

A GEOPHYSICAL INVESTIGATION OF THE SEISMICITY OF THE CLARK HILL RESERVOIR VICINITY

Quarterly Progress Report No. 17

June 1, 1979 to August 31, 1979

Leland T. Long
School of Geophysical Sciences
Georgia Institute of Technology
Atlanta, Georgia 30332

Report Due Date August 31, 1979
Submitted February 1980

PREPARED FOR THE U. S. NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR REGULATORY RESEARCH
UNDER CONTRACT NRC-04-77-211

A Geophysical Investigation of the Seismicity of the Clark Hill Reservoir Vicinity

Quarterly Progress Report No. 17

Abstract

Seismic monitoring continued at CH5, CH6, and ETG. One vertical electrical sounding and two horizontal profiles were attempted. An attempt to obtain spectral and 3-component data was made at Monticello reservoir. The gravity study of the Belair fault area was incorporated into a gravity study of the area along the COCORP reflection line. Bill Volz completed his masters thesis on the inversion of teleseism arrival times. The Maximum Entropy Spectral Analysis technique for surface wave analysis was tried out on short period data obtained from the Wallace Dam Seismic Net. During this period a sequence of events occurred in southeast Tennessee and an aftershock survey of these events was initiated.

Scope of Investigation

To determine the relation between geology and seismicity and to determine the tectonic environment that is responsible for earthquakes in theClark Hill Reservoir vicinity by continuing to monitor seismic activity rates versus water level in the Clark Hill Reservoir area and to locate seismic events. During periods of increased activity, portable instruments will be used to compute locations, focal mechanisms and spectral signature. Stations CH5 and CHλ will be maintained in continuous operation. Three RF stations will be operated in the area of the earthquake of August 2, 1974 (Mag 4.3) to provide locations and origin times for the continuing aftershocks. Data from these stations will be coordinated with proposed U.S. Corps of Engineers net in the Richard B. Russell reservoir area. One station will be maintained (ETG) to monitor the activity near Lake Sinclair in conjunction with continued operation of the Wallace Dam net WDG (expanded to 3-component) GBG, REG and one new station to improve location of events in the Lake Sinclair area. A suite of our portable smoked paper recording seismographs will be used intermittently in areas of special interest. Areas of special interest will be surveyed using the direct current electrical resistivity sounding to typical depths of the earthquakes (0.5 to 1.0 km) to determine penetration by ground water. Areas in the yet unfilled Richard B. Russell reservoir area (directly north of CHRA) will be similarly surveyed.

Results of Investigation During Quarter

Recording Summary: Seismic monitoring continued without major interruption at CH5 (double branches in southern part of the CHRA) and at CH6 (near Goshen in the northern part of the CHRA). Station EP1 was returned to Georgia Tech for revision and repair in instrumentation and was reinstalled in the field by July 19, 1979. A log of the seismic activity was maintained for the aftershock zone of the August 2, 1974 earthquake. The rate of activity was approximately 4 per week and consisted of short swarms of events. No marked changes in water level occurred during the period.

Station ETG has been recording in the Lake Sincalir area. Events located by ETG and the Wallace Dam Net funded by Georgia Power Company, for the period of June 1, 1979 to August 31, 1979 are shown in figure 2. Only two events and one questionable event were recorded during the period.

All the local and regional data recorded at stations operated out of Georgia Tech have been tabulated and important data have been made available for publication in the Southeast United States Seismic Network Bulletins.

Seismic Surface Wave Velocity Determination: The Maximum Entropy Spectral Analysis techniques for surface wave disperion measurement was tested on long period records from seven events ranging from 20 to 140 degrees distant. These events were analyzed by the traditional multiple filter technique as well as by MESA technique to allow comparison. In all cases the resolution (determined by the width at the half amplitude height of the spectral amplitude peaks) was improved by at least one order of magnitude. Figure 26-27 show a typical result taken from Wasim Munasfi's M.S. thesis now in preparation. The MESA technique was also applied to short period surface waves recorded at the WPG array as a test of the proposed procedure for the study of velocity in the CHRA. The technique was able to identify first and second higher modes as well as the fundamental mode group velocity. The data are currently being interpreted for crustal velocity structure.

A Study of Deep Crustal Structure: During this period the study by Bill Volz concerning the use of teleseismic arrival time data to interpret deep crustal and upper mantle structure was completed as a masters thesis. The traveltime inversion was accomplished by a technique similar to that used by Aki. A summary from Bill Volz's thesis is attached. Significant results of his work include modification of the technique, the identification of velocity anisotropy in the mantle and the possible existance of a zone of low velocity material dipping to the southeast at 40±20 degrees.

Focal Mechanisms using S-wave Polarization Angles: The computer program originally written by Guinn was examined for revision to include S-wave polarization. It was decided that a significant revision would be required. An attempt to obtain useful data was made August 6-8, 1979. Because of low level of activity in Lake Sinclair and CHRA it was decided to obtain data from the Monticello Reservoir area in South Carolina. That area has produced many large (m = 1.0 to 2.0) events recorded at the CHRA seismic stations. This data will be analyzed for polarization angle of the S-wave next quarter.

Resistivity Survey: On June 16, June 29 and July 22, 1979 attempts were made to obtain resistivity data. The June 16 trip obtained data for the vertical electrical sounding No. 4. On June 29 we attempted a horizontal profile. The July 22 attempt was aborted because of thunder storm activity.

Gravity Survey of Belair Fault Area: During this quarter Michael Obaoye completed his masters thesis titled "Interpretation of Detailed Gravity Traverses Across Northeastern Georgia". His traverse included the data obtained in the CHRA and Belair fault vicinity as part of this project. His interpretation of a line extending southeast of the vicinity of the Belair fault does not note any evidence of the Belair fault in either magnetic or gravity data. This indicates that the Belair fault may not be a significant crustal feature where it has been observed near the surface.

Seismicity: The manuscript for a paper given last quarter at the "Symposium on the Petroleum Geology of the Coastal Plain" was completed this quarter. A copy has been sent under separate cover.

On August 14, 1979, a magnitude 3.5 event occurred in southeastern Tennessee. This event was preceeded by two smaller events on July 19 and July 29. Georgia Tech initiated an aftershock survey using portable smoke paper seismographs immediately following the event. With assistance from TVA and an additional station provided by TEIC a 4 station array was maintained until September 18, 1979.

Progress During Quarter: The progress during the quarter was limited to individual efforts related to masters thesis and related studies because of the lack of funds caused by the delay in contract completion.

Efforts Expended During Quarter: The principle investigator expended an average of 20 percent time on the project during the quarter. One electronics technician expended about 20 percent time during the quarter. No graduate students were supported during this quarter.

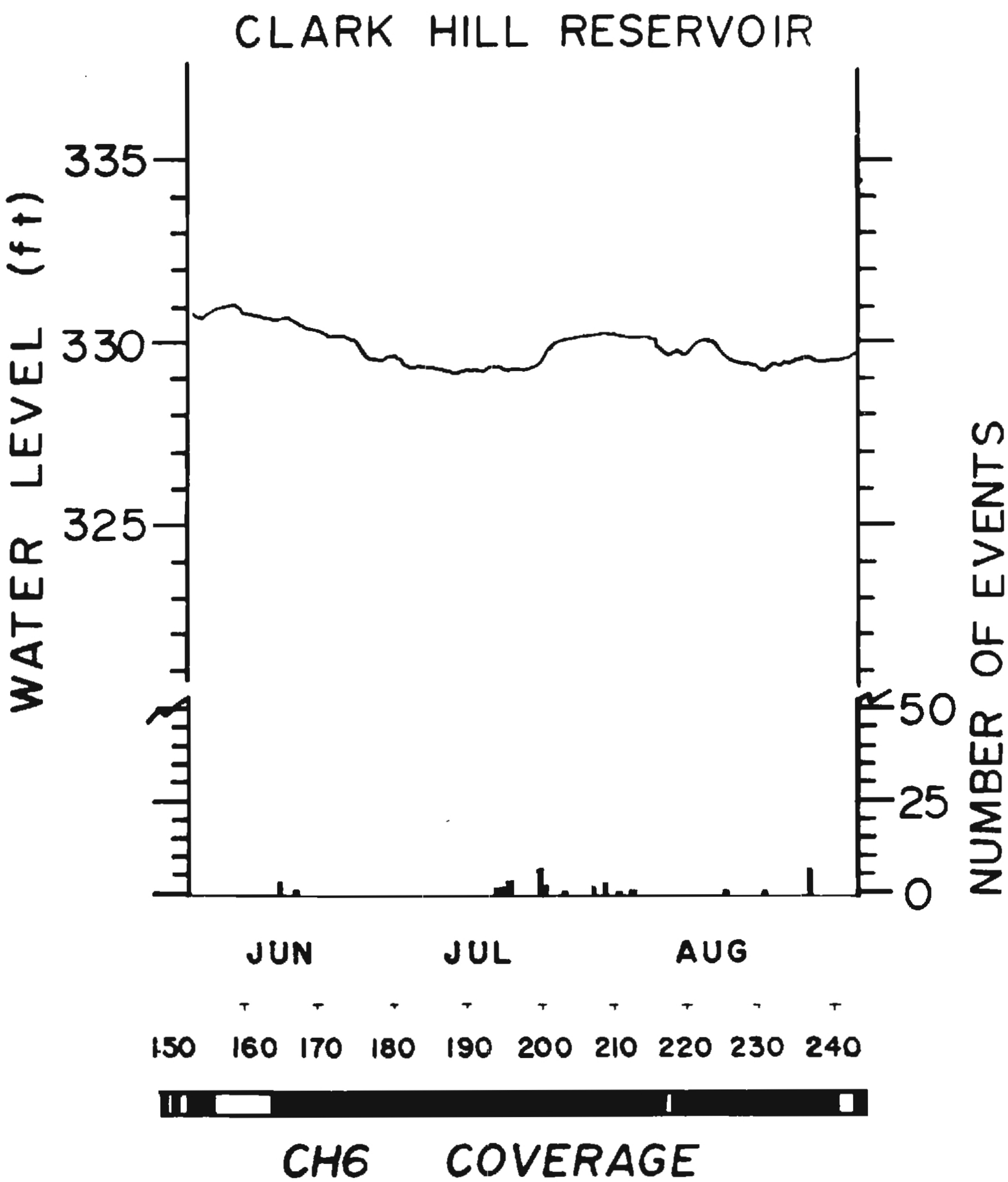

Figure 1. Log of activity versus water level for the Clark Hill Reservoir area.

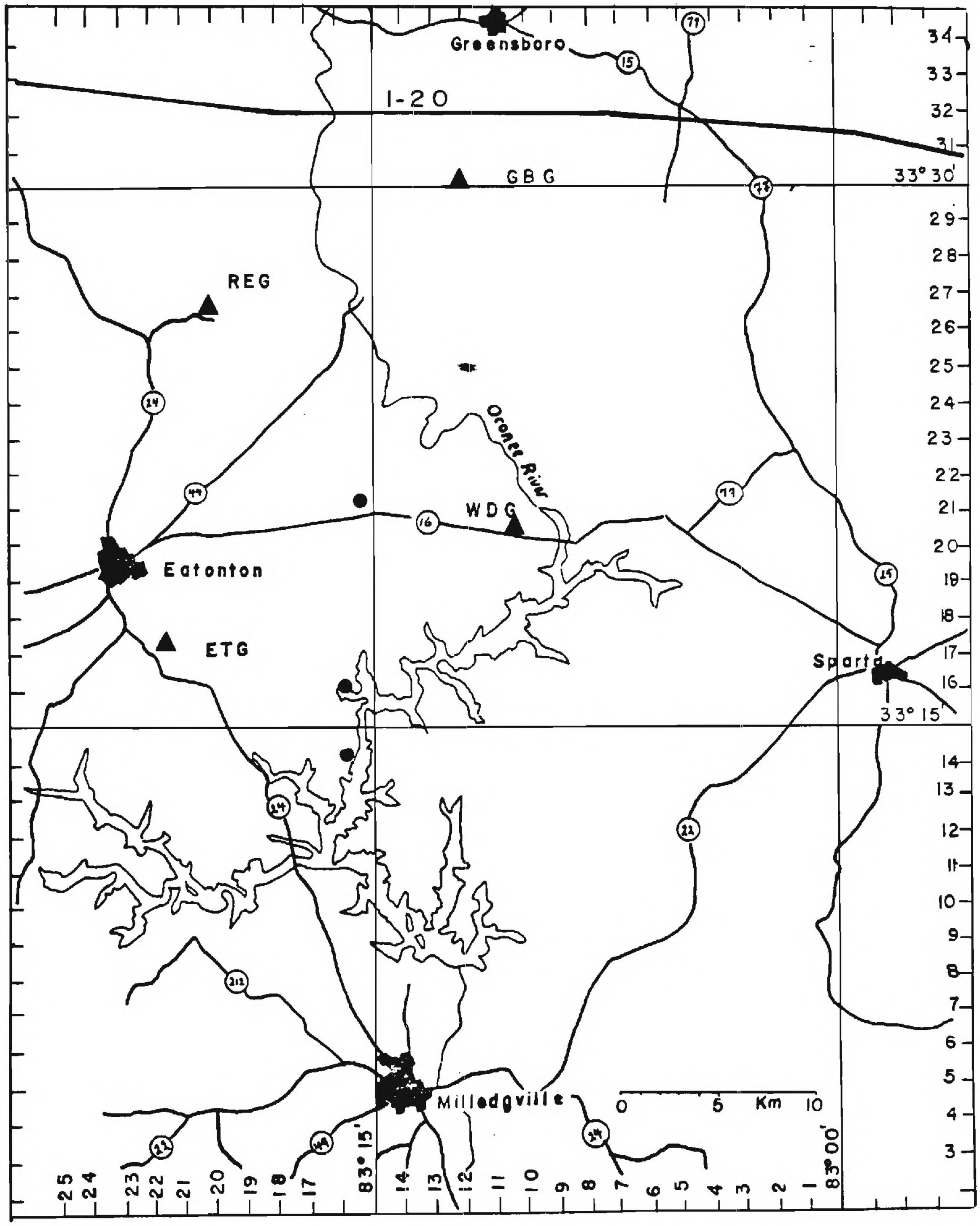

Figure 2. Earthquakes located in the Lake Sinclair region with the help of station ETG. Dots indicate earthquake location.

SUMMARY

Arrival times from earthquakes recorded at stations in the southeastern United States depend on the azimuth to the event. The purpose of this study was to identify the cause of this azimuthal variation. In order to determine the cause, 531 arrival times from 70 earthquakes were used to compute seismic travel time perturbations by a three dimensional least-squares reduction technique. Since in the travel time equations proposed by Aki et al. (1977), the coefficient matrix relating arrival time residuals to the velocity structure is singular, additional information is required to obtain a solution. Rather than use a generalized inverse technique or a damped least squares technique, as were used in previous studies, a set of constraint equations were used. The constraint chosen requires the mean perturbation in each layer to be zero. Since the mean of the arrival time residuals for each event is usually non-zero, these mean residuals were also included in the least-squares reduction.

In order to determine the characteristics of the method of solution, solutions were computed using artificial event data. These artificial data were designed to simulate the real data as closely as possible and the artificial perturbations were computed using spherical zones of

anomalous velocity. The model used to compute the artificial perturbations was chosen independently of the model used to calculate the solutions, thereby eliminating effects of similar calculation techniques. The results of the artificial data indicate that reasonable solutions are possible using these constraint equations. The results of this study using real data indicate three causes for the azimuthal variation in arrival time: 1) alignment of the fastest crystallographic direction (a-axis) of olivine crystals in a northwest-southeast direction, 2) thickening of the crust under the Appalachian Mountains and 3) a zone of low velocity material about 150 kilometers thick in the mantle dipping at about 40±20 degrees southeast.

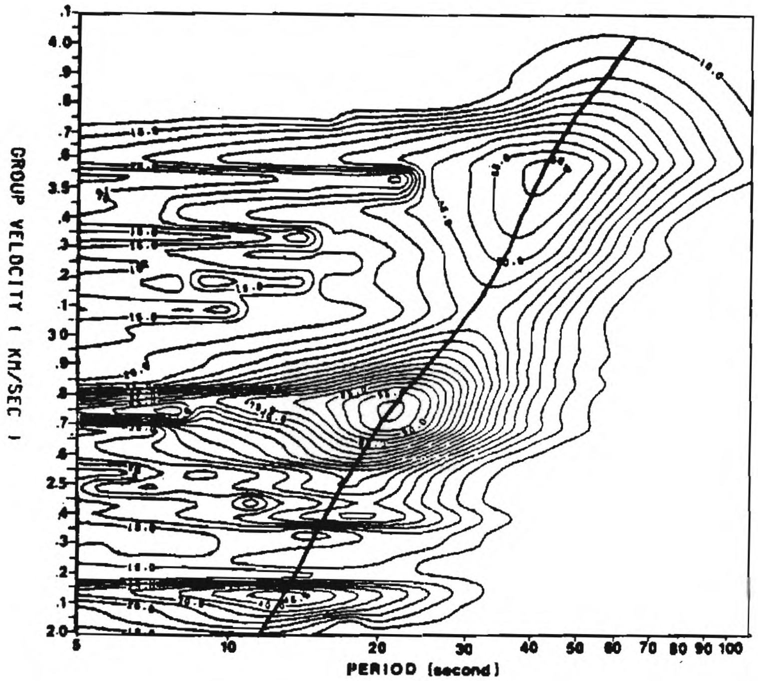

Figure 26. FSAMF Result of the Event of April 9, 1970 (off Coast of Chiapas, Mexico).

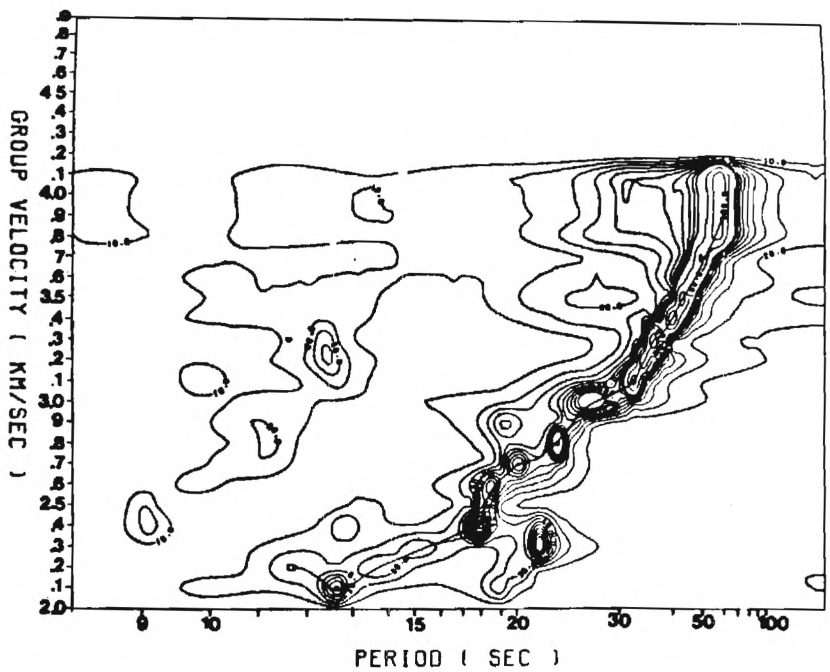

Figure 27. MESA Result of the Event of April 9, 1970 (off Coast of Chiapas, Mexico).

NUREG-0022
G35-662

A GEOPHYSICAL INVESTIGATION OF THE SEISMICITY OF THE CLARK HILL RESERVOIR VICINITY

Quarterly Progress Report 18
September 1, 1979 to November 30, 1979

and

Annual Progress Report
December 1, 1978 to November 30, 1979

Leland Timothy Long
School of Geophysical Sciences
Georgia Institute of Technology
Atlanta, Georgia 30332

Report Due Date November 30, 1979
submitted April, 1980

PREPARED FOR THE U.S. NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR REGULATORY RESEARCH
UNDER CONTRACT NRC-04-77-211

A Geophysical Investigation of the Seismicity of the Clark Hill Reservoir Vicinity

Quarterly Progress Report No. 18

Abstract

Seismic monitoring continued at CH5. Station CH6 suffered a direct lightning strike October 5, 1979 and was out of operation until November 11, 1979. EP1, which is RF transmitted to CH6 was out of operation until November 24, 1979. One horizontal Electrical Profile was attempted on November 3, 1979. The computer program to find valid focal mechanism solutions was revised to include S-wave polarization data. The study of the application of Maximum Entropy Spectral Analysis to surface wave analysis was completed. Field monitoring and preliminary analysis of the aftershocks of the East Tennessee earthquake continued through September 19, 1979.

Scope of Investigation

To determine the relation between geology and seismicity and to determine the tectonic environment that is responsible for earthquake in the Clark Hill Reservoir vicinity by continuing to monitor seismic activity rates versus water level in the Clark Hill Reservoir area and to locate seismic events. During periods of increased activity, portable instruments will be used to compute locations, focal mechanisms and spectral signature. Stations CH5 and CH6 will be maintained in continuous operation. Three RF stations will be operated in the area of the earthquake of August 2, 1974 (Mag. 4.3) to provide locations and origin times for the continuing aftershocks. Data from these stations will be coordinated with proposed U.S. Corps of Engineers net in the Richard B. Russell reservoir area. One station will be maintained (ETG) to monitor the activity near Lake Sinclair in conjunction with continued operation of the Wallace Dam net WDG (expanded to 3-component) GBG, REG and one new station to improve location of events in the Lake Sinclair area. A suite of four portable smoked paper recording seismographs will be used intermittently in areas of special interest. Areas of special interest will be surveyed using the direct current electrical resistivity sounding to typical depths of the earthquakes (0.5 to 1.0 km) to determine penetration by ground water. Areas in the yet unfilled Richard B. Russell reservoir area (directly north of CHRA) will be similarly surveyed.

Results of Investigation During Quarter

Recording Summary: Seismic monitoring continued without major interruption at CH5 (double branches in the southern part of the reservoir). Continuous recording at CH6 (near Goshen in the northern part of the reservoir) and station EP1 in the epicenter area of the August 2, 1974 earthquake was achieved during September 1979. A lightning strike at the CH6 and EP1 mixer site halted recording at CH6 for the period of October 5, 1979 to November 11, 1979 and at EP1 for the period of October 5, 1979 to November 24, 1979.

A log of the seismic activity was maintained for the aftershock zone of the August 2, 1974 earthquake. Figure 1 shows the number of events recorded at CH6 (or it's equivalent) versus water level for the period September 1, 1979 to November 30, 1979. Data from station CHF (U.S. Army Corps of Engineers) were obtained to verify activity during periods of no coverage at CH6. The seismic activity was low and consisted of a few isolated events. The water level during the period decreased slightly.

Station ETG has been recording in the Lake Sinclair area. Events located by ETG and the Wallace Dam net funded by Georgia Power Company are shown in Figure 2. The swarm of activity located about 5.0 km southwest of ETG occurred in early November. Aftershock monitoring was initiated as soon as possible and resulted in the recording and location of one event even though the field net of portable seismometers was located 3 km southeast of the swarm.

All of the local and regional data recorded at stations operated out of Georgia Tech have been documented and have been made available for publication the the Southeast United States Seismic Network Bulletin.

<u>Seismic Surface Wave Velocity Determination</u>: The thesis by Wasim Munasfi entitled "Maximum Entropy Spectral Analysis of Surface Wave Dispersion" was completed and copies are attached to this report. One significant difficulty in group velocity measurement has been the precise determination of the arrival time of surface waves of a given period. Conventional spectral analysis techniques require such a long data sample for reasonable resolution of period that the velocity retain a significant uncertainty. However, Wasim Munasfi in his thesis introduces the use of maximum entropy spectral analysis which is appropriate for short data segments. The result is an order of magnitude improvement in resolution of the seismic group velocity or period of wave arriving at a given time. Use of MESA on short period data (0.1 to 1.0 seconds) of surface waves from quarry blasts in the Georgia Piedmont resulted in the detection of first and second shear modes as well as the fundamental Rayleigh mode. Furthermore, the observed dispersion curves agree with the velocity model developed from refraction data for the Clark Hill Reservoir area. A talk summarizing Wasim Munasfi's thesis was presented at the Eastern Section, Seismological Society of America meeting.

<u>Source Mechanism Solutions using S-wave Polarization Data</u>: Revision of the computer program to find valid focal mechanism solution to a finite set of P-wave first motions and S-wave polarization angles was completed and tested. A description of the program revisions is to be part of a masters thesis by Gordon Smith. An additional three days of field data were obtained November, 14-16, 1979 in the Monticello, S.C. reservoir area. Sufficnet data were obtained to allow location and P-wave focal mechanism solutions to complement the S-wave polarization angles. In the interpretation, three-component tape recorded data were digitized and analyzed in the form of particle motion diagrams. The particle motion diagrams allowed direct interpretation of the polarization angle for linear motions. At angles of incidence where the particle motion is non-linear, the elipticity of the particle motion could be used in determination of polarization angle. The preliminary results for this study were presented as a talk at the Eastern Section, Seismological Society of America meeting.

Spectral Analysis Studies: The study of a seismic spectral discriminant for reservoir induced earthquakes, funded by the USGS, was completed during this quarter. The summary of results from the study are attached to this report. Of particular note are two observations. First, a spectral decay proportional to the square of the frequency is (with the limited data) able to predict where reservoirs will induce seismic activity. Second, high quality data are sparce and greater efforts should be made to record data amenable to spectral analysis in the vicinity of reservoirs. This study grew out of results from the CHRA study. Greg Johnston is developing a source model for reservoir induced earthquakes as part of his masters thesis which should be complete next quarter. Data obtained at Monticello reservoir were used for spectral analysis as well as above in the focal mechanism solution. The preliminary results of Greg Johnston's thesis were presented at the Eastern Section, Seismological Society meeting.

Resistivity Studies: On November 3, 1979 a horizontal resistivity profile was attempted in the epicenter area. The profile was to traverse the epicenter perpendicular to on the proposed zones of faulting.

Thermoelastic Stress Analysis: An attempt was made to refine the computations of thermoelastic stress associated with fluid flow in an open crack under a reservoir. The analysis was designed to evaluate temperature changes when a thermal gradient exists. The results indicate that the temperature at depth can begin to change immediately when a gradient exists. Hence, with sufficient fluid flow, stresses on the order of 3 to 30 bars can be generated within 3 to 6 months. It is significant to note that we have observed stress drops of less than one bar in reservoir areas like Jocassee and Clark Hill. Final results will have to be delayed until a revised program to compute stress can be developed.

Seismicity: Field monitoring for aftershocks of the 13 August 1979 earthquake in southeastern Tennessee was halted 18 September 1979. One aftershock was recorded on 15 August 1979 with a depth of 6.5±1.0 km. This depth places the event in the upper part of the underthrust plate below the sediments identified in the COCORP reflection data. The results were presented at the Eastern Section, Seismological Society of America meeting. An abstract is attached.

Progress During Quarter: Progress during the quarter was limited to the preparation of talks and coordinated work on masters thesis and related projects. Resistivity survey was delayed because of instrumentation difficulties and weather.

Efforts Expended During Quarter: The principle investigator expended an average of 20 percent time on the project during the quarter. One electronics technician expended approximately 20% time during the quarter and two graduate research assistants worked at one-half time each for two months.

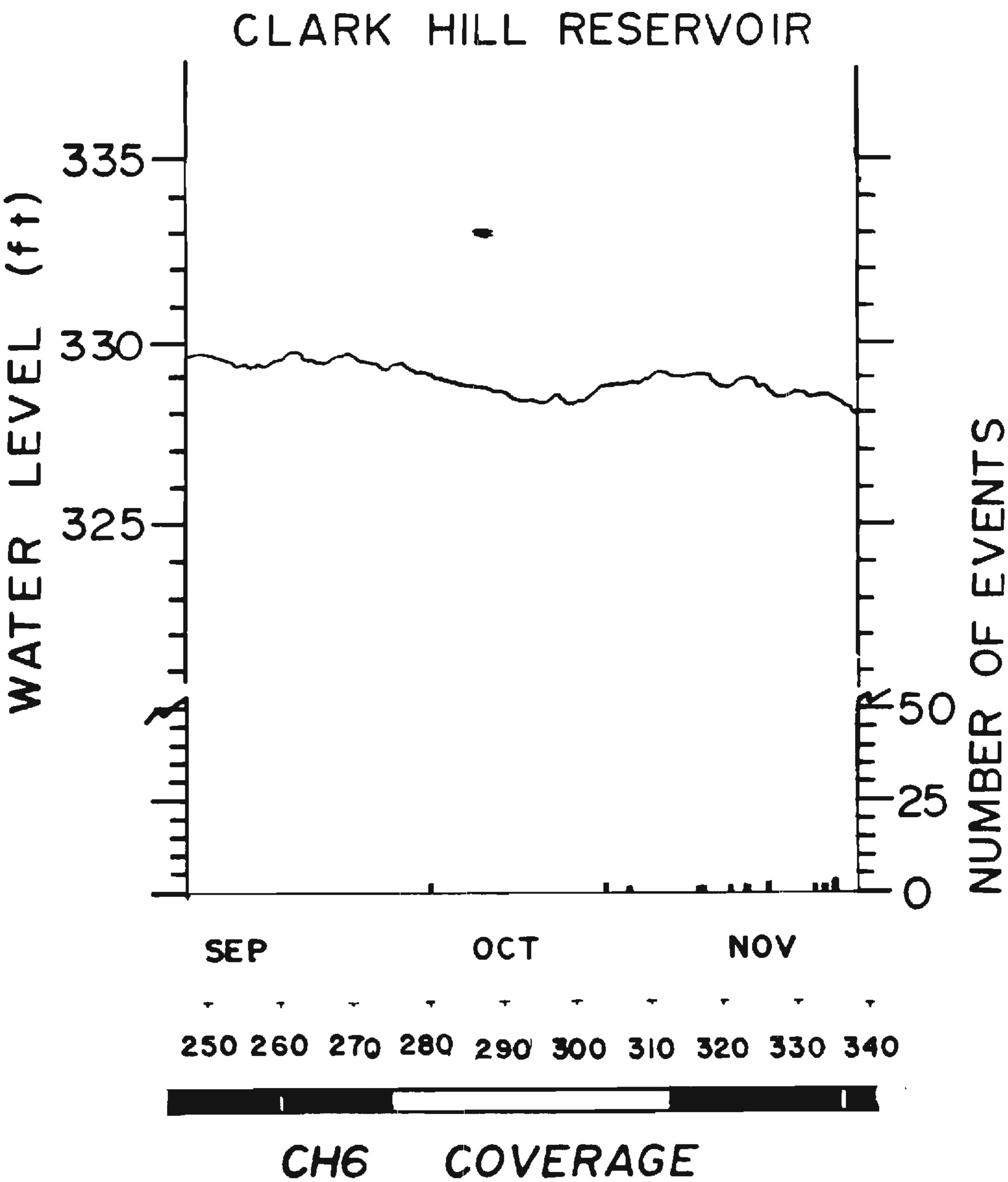

Figure 1. Log of activity versus water level for the Clark Hill Reservoir area.

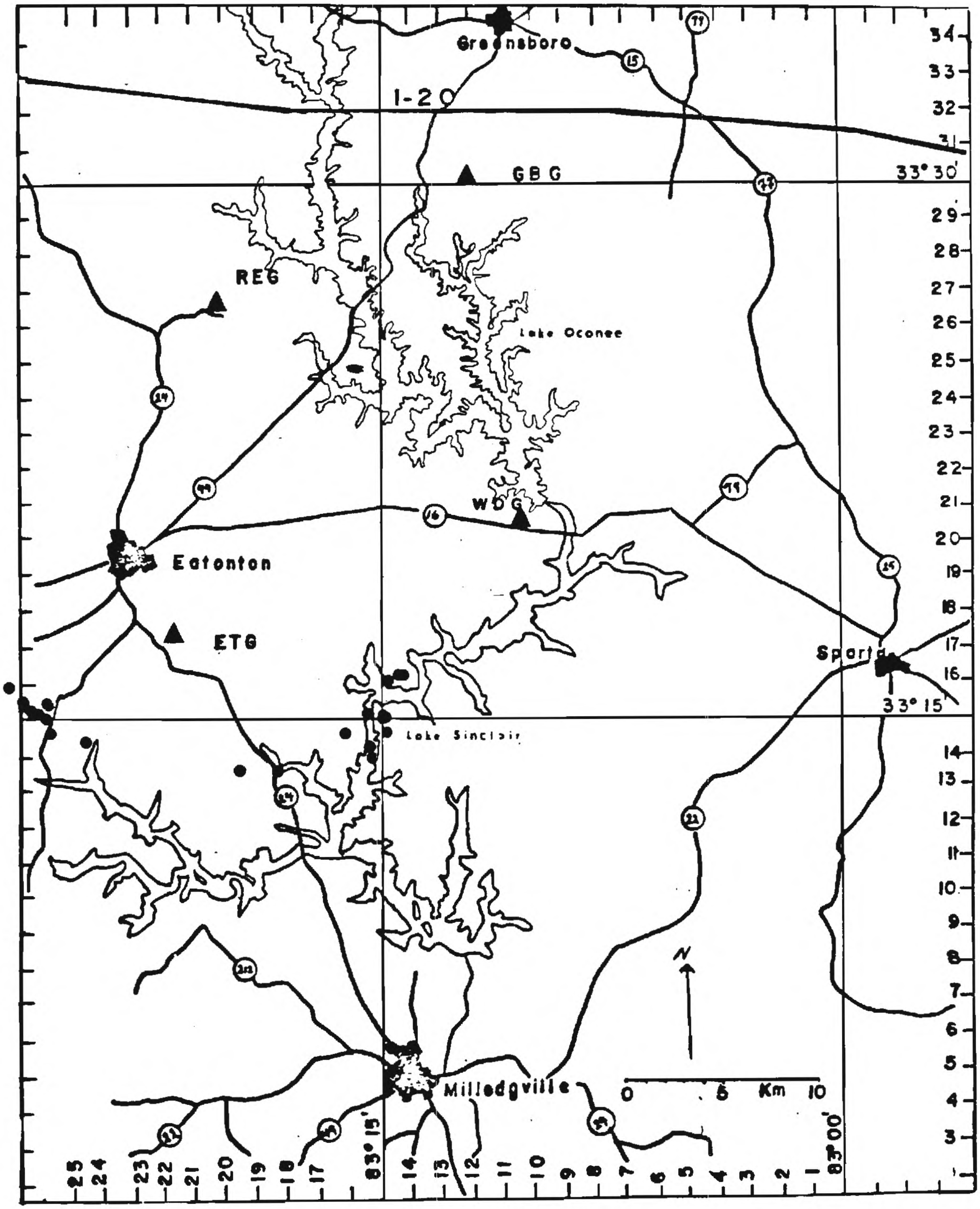

Figure 2. Earthquakes located in the Lake Sinclair region with the help of station ETG. Dots indicate earthquake location.

EVALUATION OF A SEISMIC SPECTRAL DISCRIMINANT FOR RESERVOIR INDUCED EARTHQUAKES

Gregory L. Johnston and L. T. Long, School of Geophysical Sciences, Georgia Institute of Technology, Atlanta, Georgia, 30332.

A high frequency displacement spectral slope proportional to ω-cube may be useful in discriminating areas susceptible to reservoir induced seismic activity. In contrast, earthquakes with lesser slopes (ω-square) may be typical of areas where reservoir do not induce seismic activity. To test this spectral discriminant for reservoir induced earthquakes, we have attempted to gather seismic spectral data from as many reservoir areas as possible.

Limitations on the computation of spectra are imposed by seismic system gain and frequency response. The effects of frequency dependent attenuation, Q, on the higher frequencies can also be significant. WWSSN SP data are found to be usable only in a narrow magnitude and distance range in high Q regions. Typical telemetry system recordings of earthquakes of magnitude 2.0 ± 0.3 at distances of 20 to 50 km in regions where Q is greater than 400 are found to be suitable. A tape system which can measure the spectral slope in the 30 to 200 Hz range has been used for very close events in the southeast United States. Several reservoir areas which have exhibited induced seismicity in the southeast United States have been characterized by an ω-cube high frequency displacement slope. Lack of appropriate data has delayed identification of other ω-cube areas.

THE SOUTHEAST TENNESSEE EARTHQUAKE OF 13 AUGUST 1979

R. A. Binford, Gordon Smith, Anton Dainty, and L. T. Long, School of Geophysical Sciences, Georgia Institute of Technology, Atlanta, Georgia, 30332

A small earthquake of local magnitude 3.7 occurred in southeast Tennessee at 05:18:56.8 UT on 13 August 1979. Seismic arrivals at regional stations indicate a location of $35^{\circ}13'$N, $84^{\circ}23'$W, 20 km south southwest of Tellico Plains, Tennessee. Within one day the Tennessee Earthquake Information Center and Georgia Tech jointly established a four station microearthquake aftershock survey. One aftershock was recorded on 15 August 1979 and was located at $35^{\circ}14.01'$N, $84^{\circ}23.58'$W and 6.5 ± 1.0 km deep. The aftershock occurred 22.5 km southwest (along strike) of the COCORP seismic reflection survey. By comparison with the COCORP structural profile, the 6.5 km depth indicates a hypocenter below the underthrusted sediments and in the upper part of the underthrusted plate.

MAXIMUM ENTROPY SPECTRAL ANALYSIS OF SURFACE WAVE DISPERSION

W. Manasfi, L. T. Long, School of Geophysical Sciences, Georgia Institute of Technology, Atlanta, Georgia, 30332

Surface wave dispersion has been analyzed usually through the utilization of the multiple filter technique. However, in the application of the multiple filter technique the spectral resolution is limited in the analysis of short data segments, and by the choice of the filter bandwidth. Conventionally, the limitation imposed by the short data length is overcomed by the cyclic extension of the data, and the optimum filter bandwidths are chosen, theoretically, on the basis of a preknowledge of the group velocity. However, the dispersed surface wave when sampled by a short time segment is band limited, and a consideration of the time series model of the seismogram as an autoregressive process rather than a moving average suggests the utilization of the Maximum Entropy Spectral Analysis (MESA). In MESA higher resolution, for short time segments, is acquired through the recursive computation of a whitening filter directly from the data.

In this study the MESA is utilized, through a simplification of the moving window technique, in the study of the group velocity dispersion of Rayleigh and higher shear modes. Dispersion curves for seven teleseismic events, covering a wide geographical distribution were computed for a comparison of MESA technique with the results of the multiple filter technique and the peak and trough method. The MESA provided significant enhancement of the spectral resolution over the multiple filter technique, and the peak and trough method. The MESA was then used to measure dispersion of short period (0.1 - 1.0 second) Rayleigh, and two higher shear modes in the Georgia Piedmont Province.

A COMPUTER METHOD FOR DETERMINATION OF VALID FOCAL MECHANISMS USING P-WAVE FIRST MOTIONS AND S-WAVE POLARIZATION

Gordon Smith and L. T. Long, School of Geophysical Sciences, Georgia Institute of Technology, Atlanta, Georgia, 30332

A computer program (Guinn and Long, Earthquake Notes, 1977) which used P-wave first motions to define valid P, T, and B axis for a double couple without moment source has been modified to include S-wave polarization data. The method systematically tests all possible focal mechanism for agreement with the observed data. At each P, T, and B axis orientation theoretical S-wave polarization angles are computed for each position on the focal sphere sampled by the observed data. If the observed and theoretical polarization angles are within a preset value (typically 10 degrees) then the S-wave polarization is assumed to be consistent with the focal mechanism under test. The program was tested on the North Atlantic earthquake of August 3, 1963 (see Stauder, 1963) using 26 P-wave first motions and 27 S-wave polarizations. The domain of valid focal mechanisms contained the published solution.

The program is currently being applied to S-wave data obtained from microearthquakes in the southeastern United States. The non-linearity of the particle motion of the S-wave limits direct measurement of the S-wave polarization to data obtained at distances from the epicenter of less than 0.7 times the focal depth. For arrivals at greater distances, particle motion diagrams in the horizontal plane are plotted to facilitate an interpretation of the S-wave polarization angle by comparison with theoretical horizontal particle displacments.

Final Technical Report

"A Seismic Spectral Discriminant for Reservoir Induced Earthquakes"

Leland Timothy Long and Greg Johnston

December 21, 1979

Project Summary

The object of this research has been to evaluate a spectral discriminant which might allow identification of other areas where new reservoirs would induce significant seismic activity. The discriminant is the high-frequency slope of the displacement spectra of earthquakes occurring in the vicinity of a new or proposed reservoir. An ω-cube slope from earthquakes in the vicinity would predict that nearby reservoirs would induce earthquakes and an ω- square slope from earthquakes in a region would predict that reservoirs in the vicinity would not induce earthquakes. This association of ω-cubic decay with induced reservoir seismic activity and ω-square decay with areas where reservoirs do not induce seismic activity was observed first in studies of seismic spectra of Southeastern United States earthquakes. Earthquakes occurring in the Folded Appalachians have an ω-square high-frequency decay and reservoirs in that region are not known to induce seismic activity. Earthquakes observed in two Piedmont Province reservoirs which have induced seismic activity show ω-cubic spectral decay. Hence, the limited data for the Southeastern United States indicated that the high-frequency spectral decay may be a viable discriminant for the identification of other areas susceptable to induced seismic activity. In this study one objective was to test the generality of the discriminant for identifying other areas of induced seismic activity.

Fundamental to this study was an investigation of whether there exists a theoretical basis for the discriminant. Most theoretical studies on the radiation of high-frequency seismic energy indicate that the high-frequency energy is controlled to a large extent by the slip velocity on the fault. At the rupture front, velocity changes which may be related to variable stress conditions or fault irregularities enrich the spectra with high-frequency energy. In contrast, a lubricated fault plane moving under low-compressive stress conditions would not possess the same intensity of high-frequency energy. Hence models of the former predict ω- square decay and models of the latter predict ω-cube decay. The latter corresponds to conditions expected for the shallow reservoir-induced earthquakes.

In our literature review only two reliable examples of spectra were found from which we could measure the high-frequency slope. Detailed spectra from the Oroville aftershock sequence show ω-cube decay giving credence to the claim that these events were reservoir induced. Spectral studies of Lake Mead earthquakes showed S-wave high-frequency decay of $\omega^{-1.2}$ to $\omega^{-1.8}$ but the conclusion of the authors was that these were natural, rather than induced, events. In an attempt to supplement the data we obtained new spectral data from southeastern United States reservoir areas. Seventeen new spectra from the Monticello (S.C.) reservoir area and 32 spectra from the Clark Hill (Georgia-South Carolina) Reservoir area were obtained. These spectra showed $\omega^{-3.0}$ decay and are from areas of induced reservoir activity. We also obtained 22 new spectra from the Lake Sinclair, Georgia, area, an area of suspected but unproven induced seismic activity. These spectra show generally a $\omega^{-2.0}$ decay. The Wallace Dam (Lake Ocoee) on the eastern branch of Lake Sinclair has been carefully monitored for seismic activity but none has been detected after one year of loading.

We were unable to come to definite conclusions concerning the spectral discriminant because of the sparsity of data. Where appropriate data could be examined, the spectral slope did discriminate areas where reservoirs induce earthquakes from areas where reservoirs do not induce earthquakes. Theoretical models of the seismic source allow a rational explanation for the discriminant based on the character of the rupture velocity and the relation between frictional resistance and driving shear stress. Models which are based on a uniform, transonic rupture along a smooth circular fault best satisfy the spectra from areas of reservoir induced seismicity. We uncovered no contradictory evidence that could not be explained. The success of the limited data and the theoretical rational are compelling circumstantial evidence supporting the discriminant.

We recommend two to three years of high-quality digital recording of seismic data prior to the filling of reservoirs. We recommend also the evaluation of spectral signatures as a function of depth to test whether this might be a significant factor in the apparent success of the discriminant.

G35-662

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G35-662

A GEOPHYSICAL INVESTIGATION OF THE SEISMICITY OF THE CLARK HILL RESERVOIR VICINITY

Quarterly Progress Report 19
December 1, 1979 to February 29, 1980

Leland Timothy Long
School of Geophysical Sciences
Georgia Institute of Technology
Atlanta, Georgia 30332

Report Due Date February 29, 1980
submitted June, 1980

PREPARED FOR THE U.S. NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR REGULATORY RESEARCH
UNDER CONTRACT NRC-04-77-211

A log of the seismic activity was maintained for the aftershock zone of the August 2, 1974 earthquake. Figure 1 shows the number of events recorded at CH6 (or it's equivalent) versus water level for the period December 11979 to February 1980. The swarm consisted of isolated events separated by a few days. The swarm coincided with a gradual decrease in reservoir water level.

Station ETG has been recording in the Lake Sinclair area. Events located by ETG and the Wallace Dam net funded by Georgia Power Company are shown in Figure 2 for the period of December 1979 through February 1980.

All of the local and regional data recorded at stations operated out of Georgia Tech have been made available for publication in the southeastern United States Sesimic Network Bulletins.

Resistivity Studies: The resistivity data obtained prior to or during the quarter have been reinterpreted and a preliminary analysis is attached. The major variations in the resistivity are related to the near-surface materials and we still do not have sufficient data to see variations at depth.

Spectral Analysis Studies: The study of spectra of southeastern United States earthquakes by George Marion has been rewritten for publication and has been accepted for the August BSSA. During this quarter Greg Johnston completed his thesis entitled "A seismic spectral discriminant for reservoir induced earthquakes in the southeastern United States". A summary of this thesis is attached.

Source Mechanism Solutions using S-Wave Polarization Data: Gordon Smith completed his Masters thesis entitled "A focal mechanism study using both P-wave first motions and S-wave polarization angles". A copy of his thesis is attached. For the application of his technique, Gordon obtained data in the Monticello reservoir area in South Carolina. The events indicate diagonal dip-slip faulting along a plane oriented N67°E; dipping 75°NW.

Seismicity: A write up and summary of our data obtained in the aftershock survey of the 13 August 1979 earthquake in southeastern Tennessee was completed and is attached.

Progress During Quarter: Progress during the quarter was limited to completion of Masters thesis and analysis of resistivity data. The weather during this time period was not conducive to resistivity studies.

Efforts Expended During Quarter: The principal investigator expended an average of 20% time on the project during the quarter. One electronics technician expended approximately 15% time and one graduate student worked at 50% time on the project during the quarter.

A Geophysical Investigation of the Seismicity of the Clark Hill Reservoir Vicinity

Quarterly Progress Report No. 19

Abstract

Seismic monitoring continued at stations CH5 and CH6. Station EP1 operated intermittantly during the quarter. An analysis of existing resistivity data has reveiled major variations in the near-surface materials. Two Masters' thesis were completed during the quarter. One concerned the use of seismic spectra to discriminate reservoirs which might induce seismic activity. The second provided an analysis technique for using shear-wave polarizations in focal mechanism studies.

Scope of Investigation

To determine the relation between geology and seismicity and to determine the tectonic environment that is responsible for earthquakes in the Clark Hill Reservoir vicinity by continuing to monitor seismic activity rates versus water level in the Clark Hill Reservoir area and to locate seismic events. During periods of increased activity, portable instruments will be used to compute locations, focal mechanisms and spectral signature. Stations CH5 and CH6 will be maintained in continuous operation. Three RF stations will be operated in the area of the earthquake of August 2, 1974 (Mag. 4.3) to provide locations and origin times for the continuing aftershocks. Data from these stations will be coordinated with proposed U.S. Corps of Engineers net in the Richard B. Russell reservoir area. One station will be maintained (ETG) to monitor the activity near Lake Sinclair in conjunction with continued operation of the Wallace Dam net WDG (expanded to 3-component) GBG, REG and one new station to improve location of events in the Lake Sinclair area. A suite of four portable smoked paper recording seismographs will be used intermittently in areas of special interest. Areas of special interest will be surveyed using the direct current electrical resistivity sounding to typical depths of the earthquakes (0.5 to 1.0 km) to determine penetration by ground water. Areas in the yet unfilled Richard B. Russell reservoir area (directly north of CHRA) will be similarly surveyed.

Results of Investigation During Quarter

Recording Summary: Seismic monitoring continued without major interruption at CH5 (double branches in the southern part of the reservoir) and at CH6 (near Goshen in the northern part of the reservoir). Station EP1 (located in the aftershock zone of the August 2, 1974 earthquake) operated continuously during December 1979. EP1 is a 4.5 Hz - three component system. EP1 operated partially during January and February 1980.

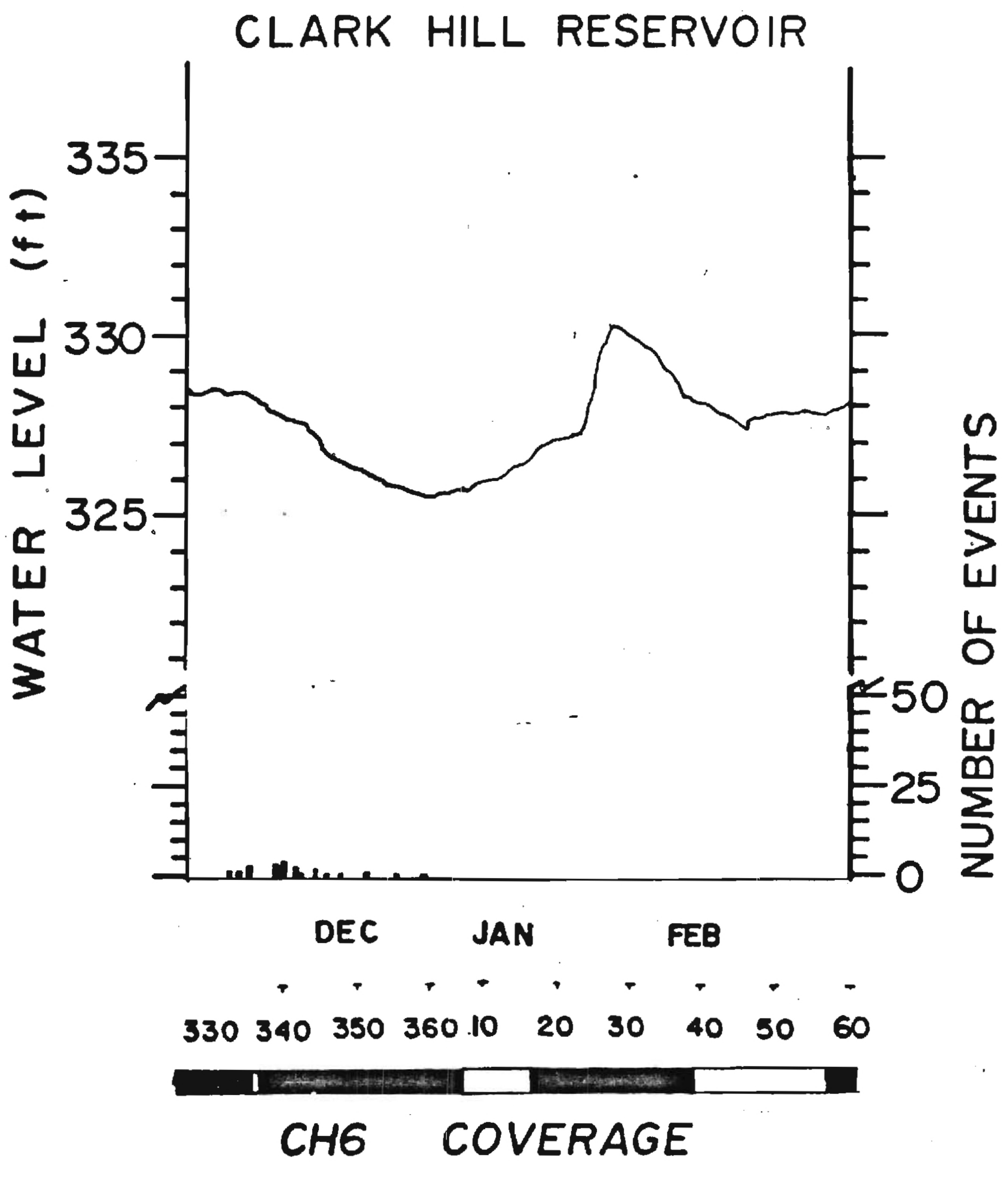

Figure 1. Log of activity versus water level for the Clark Hill Reservoir area.

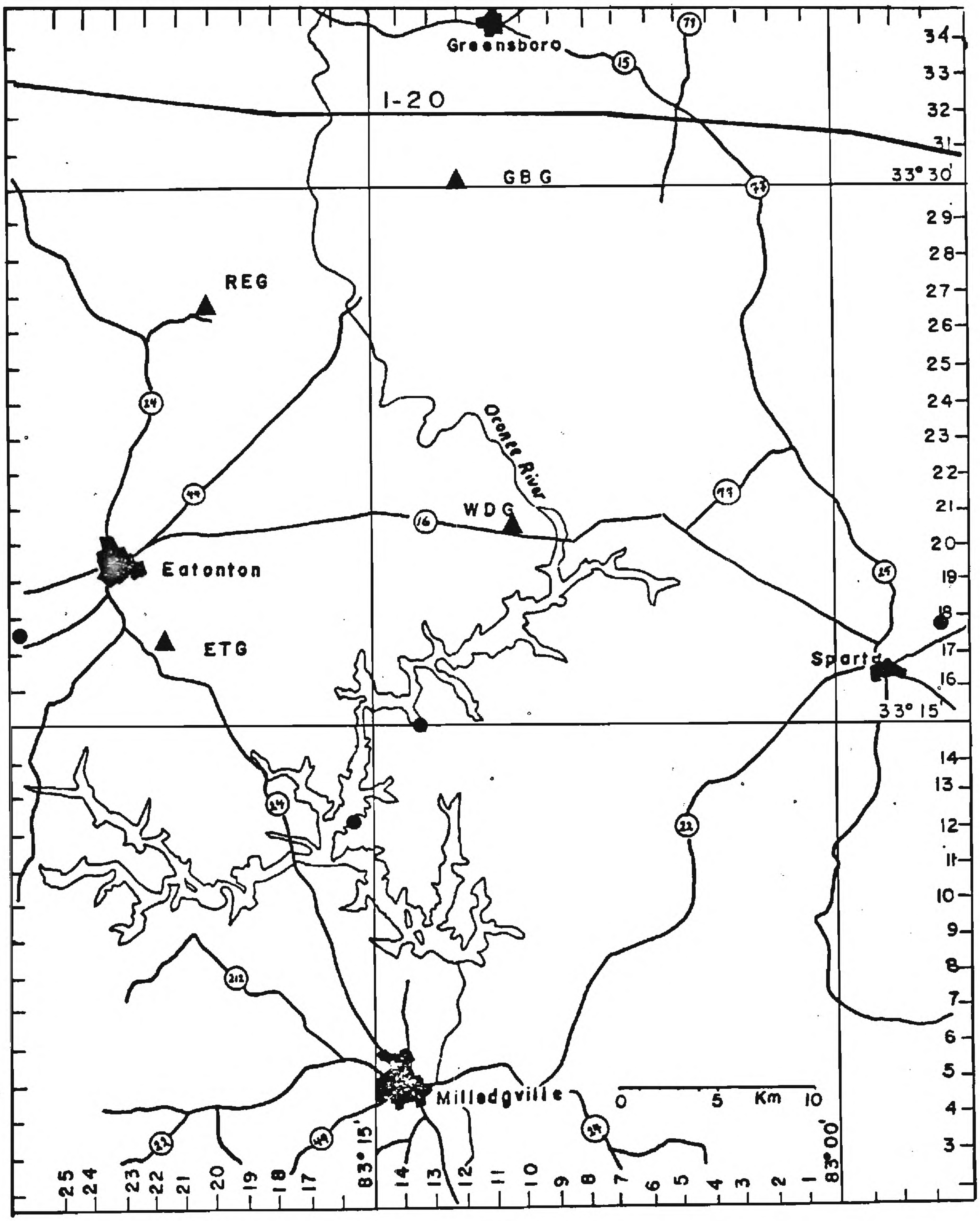

Figure 2. Earthquakes located in the Lake Sinclair region with the help of station ETG. Dots indicate earthquake location.

A SEISMIC SPECTRAL DISCRIMINANT FOR RESERVOIR INDUCED EARTHQUAKES IN THE SOUTHEASTERN UNITED STATES

by Gregory Lamar Johnston

SUMMARY

Seismic activity near Lakes Jocassee, Keowee, and Monticello in South Carolina and the Clark Hill Reservoir on the Georgia-South Carolina border has been attributed to reservoir impoundment. Many reservoirs in the southeastern United States have generated questionable or no detectable seismic activity.

A previous study of the body-wave displacement spectra of microearthquakes located near Lake Jocassee and the Clark Hill Reservoir found an ω^{-3} high-frequency decay of the amplitude spectrum. In the same study, seismic displacement spectra of earthquakes from near Maryville, Tennessee decayed as ω^{-2} at high frequencies. Reservoirs in that area of the Folded Appalachian Province have not induced seismic activity. These observations suggest that the spectral slope at high frequencies may be a useful discriminant for areas susceptible to reservoir induced earthquakes. To test these observations for use as a discriminant for reservoir induced activity in the southeastern United States, new data for which spectra could be calculated were obtained. Seventeen spectra from the Monticello Reservoir Area and 29 new spectra from the Clark Hill Reservoir area were obtained. These spectra generally decayed as ω^{-3}. Lake Sinclair, Georgia is an area of suspected but unproved induced seismic activity. Twenty-one

spectra obtained from this area generally showed an ω^{-2} high-frequency decay. The Wallace Dam (Lake Oconee) on the northeastern branch of Lake Sinclair has been carefully monitored for seismic activity but none has been detected after one year of loading.

Limitations on reliable high-frequency seismic spectral analysis are imposed by seismic system gain and frequency response. The effects of frequency dependent attenuation, represented by Q, on the higher wave frequency can bias the spectra obtained. Criteria were established to determine reliable spectral data as recorded on the seismic telemetry system operated by the School of Geophysical Sciences at Georgia Tech. The criteria are satisfied for earthquakes of magnitude $(m_b) = 2.1 \pm 0.7$ recorded at epicentral distances of 15 to 50 km in regions where Q is greater than 800. Using the method of spectral ratios, an average Q value for the Piedmont province of the southeastern United States was found to be approximately 900 for P- and 450 for S-waves.

A theoretical basis for a seismic spectral discriminant is developed. Most theoretical studies indicate that the high-frequency energy released by an earthquake is controlled to a large extent by the fault slip velocity. Velocity changes (i.e., stopping phases caused by an irregular fault plane) on the rupture front enrich the spectrum with high-frequency energy and an ω^{-2} decay is predicted. In contrast, a constant or increasing rupture velocity on a smooth fault plane would generate less high-frequency energy and the seismic spectrum consequently decays as ω^{-3}. Models based on a uniform, transonic rupture (rupture velocity greater than or equal to the S-wave velocity) along a smooth circular fault best satisfy the spectra of earthquakes from areas of reservoir induced seismicity.

The spectral discriminant, that local earthquakes whose high-frequency displacement spectra decay as ω^{-3} can define a region where reservoirs could induce seismic activity, appears to be viable in the southeastern United States. Further spectral studies are needed in this and other areas to test the generality of the discriminant.

The August 13, 1979, Southeast Tennessee Earthquake

by L. T. Long, J. Musser, Gordon Smith, Anton Dainty and Andy Binford

Introduction

On August 13, 1979 at 05:18:56.6 UT an earthquake of approximate magnitude 3.3 occurred in southeastern Tennessee about 20 km SSW of Tellico Plains. Immediately following detection of the event, investigators from Georgia Tech and the Tennessee Earthquake Information Center placed portable seismic equipment near the estimated epicenter. A four station aftershock survey was initiated August 14, 1979 and was extended to September 18, 1979 with assistance from the Tennessee Valley Authority. Following the survey additional regional seismic recordings for the main event were obtained and analyzed. The objectives of this report are to present the results of Georgia Tech's investigation of the data for the main event and from the aftershock survey.

Regional Seismicity

The epicenter of the August 13, 1979 event is located in the Valley and Ridge Province of the Appalachian Mountains near its boundary with the Blue Ridge Province (Figure 1). The area is underlain by strongly folded and faulted Precambrian to Pennsylvanian sediments. The area of southeastern Tennessee within an approximate radius of 100 km of the epicenter of the August 13, 1979 earthquake has experienced a moderate level of seismic activity. The epicenter falls within the southern Appalachian Seismic Zone of Bollinger (1973). From 1829 to 1976 there were 38 events felt in southeastern Tennessee within a radius of 100 km of the August 13, 1979 event. The largest of these occurred in March 1913 and had a maximum epicentral intensity of VII (MM) (see Figure 2).

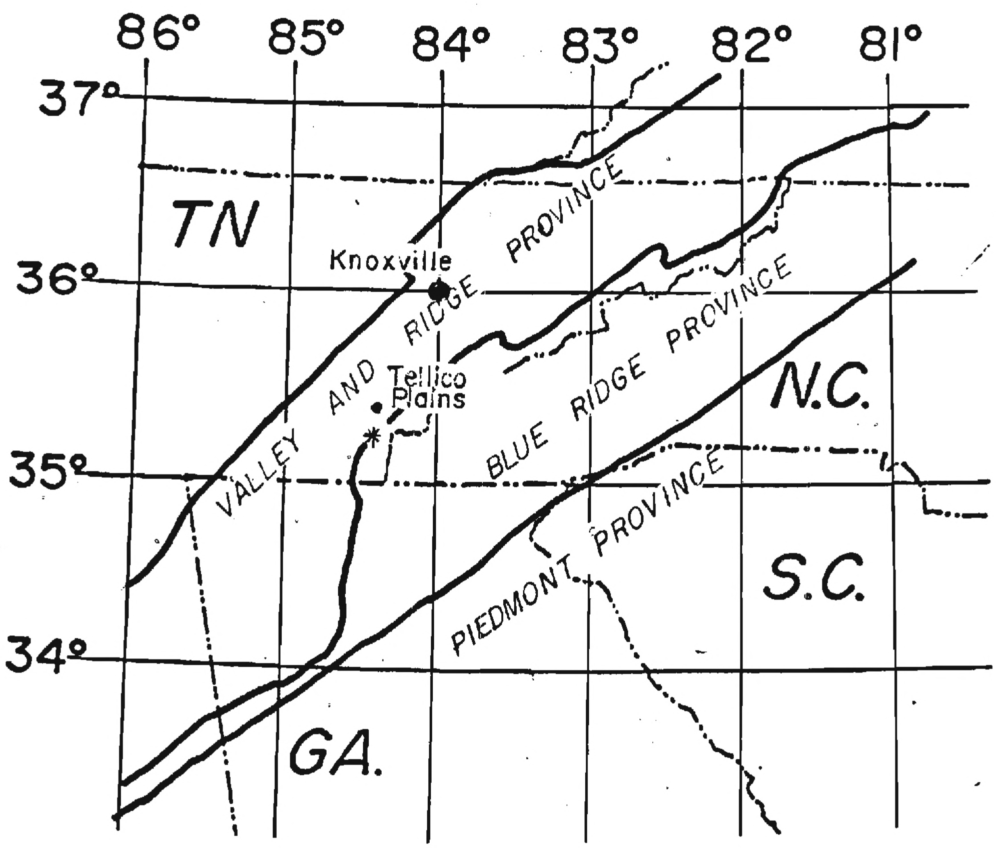

Figure 1. Location map for southeastern Tennessee.

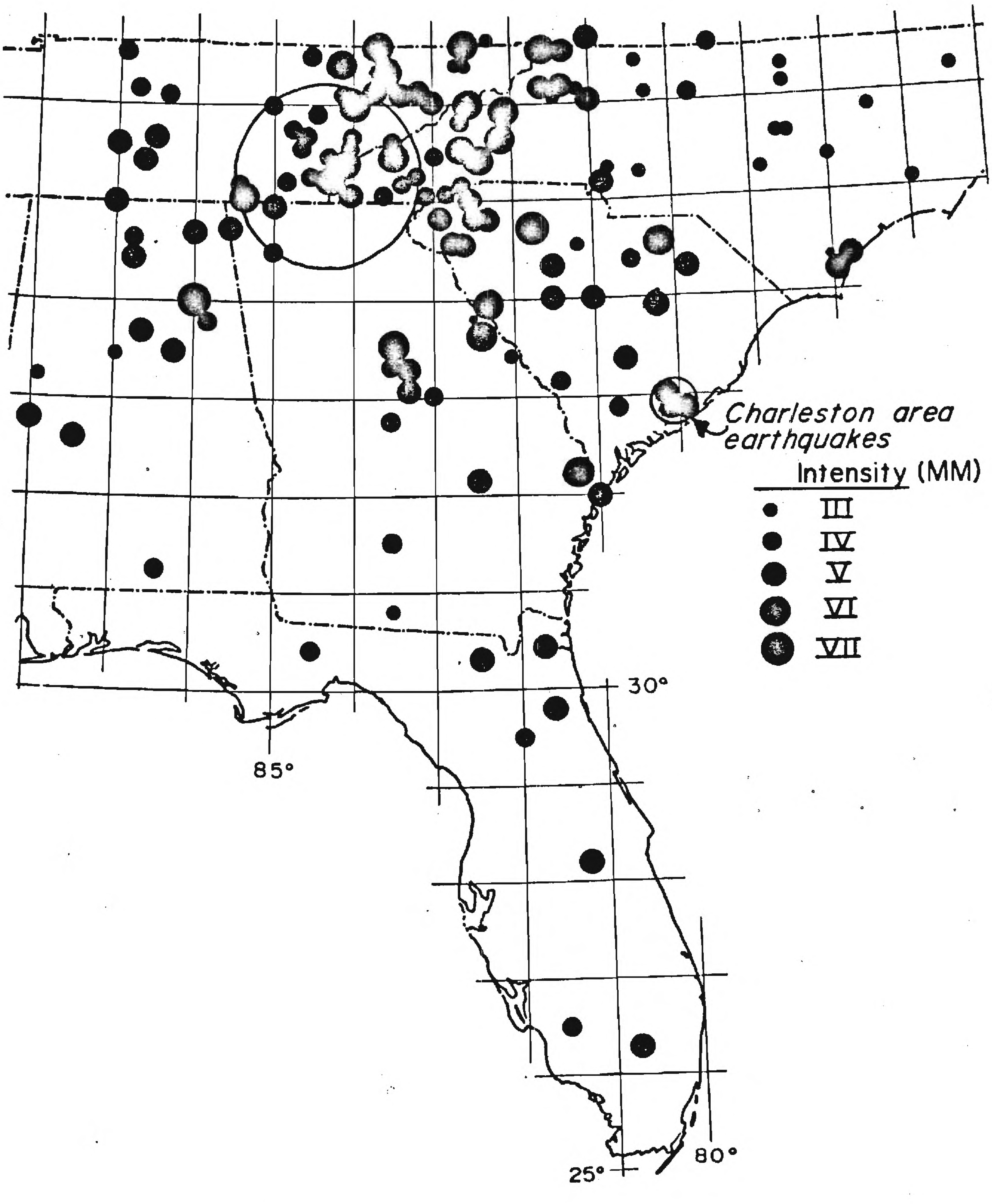

Figure 2. Regional Seismicity map. Circle denotes 100 km radius from the location of August 13, 1979 earthquake.

Intensity Survey

Immediately following the August 13, 1979 event Georgia Tech initiated an intensity survey in the immediately vicinity of the epicenter. Over 45 individual responses were obtained in the field or subsequently mailed to Georgia Tech. In addition the U.S. Geological Survey initiated a survey of post masters covering a considerably wider area. From these two sets of questionnaires, intensities were evaluated according to the Modified Mercalli scale and the felt reports are summarized in Figure 3. Table 1 is a summary of the intensity data showing the distribution of observed intensities at each community. The Intensity IV area has an approximate radius of 40 km and Intensity IV (MM) is considered the maximum intensity for the event. There were only a very few indications of Intensity V in the central area and these were not sufficient to justify a maximum intensity rating above IV. The total felt area was approximately 15,000 km^2 and the intensity IV area was about 5,000 km^2. . .

Location

Usable records for the East Tennessee event of August 13, 1979 were obtained from 15 regional seismic stations (see Table 2 for arrival times). The hypocenter determined from these arrival times is 35°13.20'N±1.91 km and 84°23.43'W ±1.63 km with an error ellipse with an area of 12.8 km^2 (see Table 2 for details). The depth of focus was 5.0 km ± 4.5 km. However, the depth of focus computation requires knowledge of the Moho depth near the epicenter. If the Moho depth is deeper than that of the model used for location (i.e. 33 km) the event may appear to be located above the surface. Hence, we modified the model in the location program to correspond to a depth of 49.6 km which

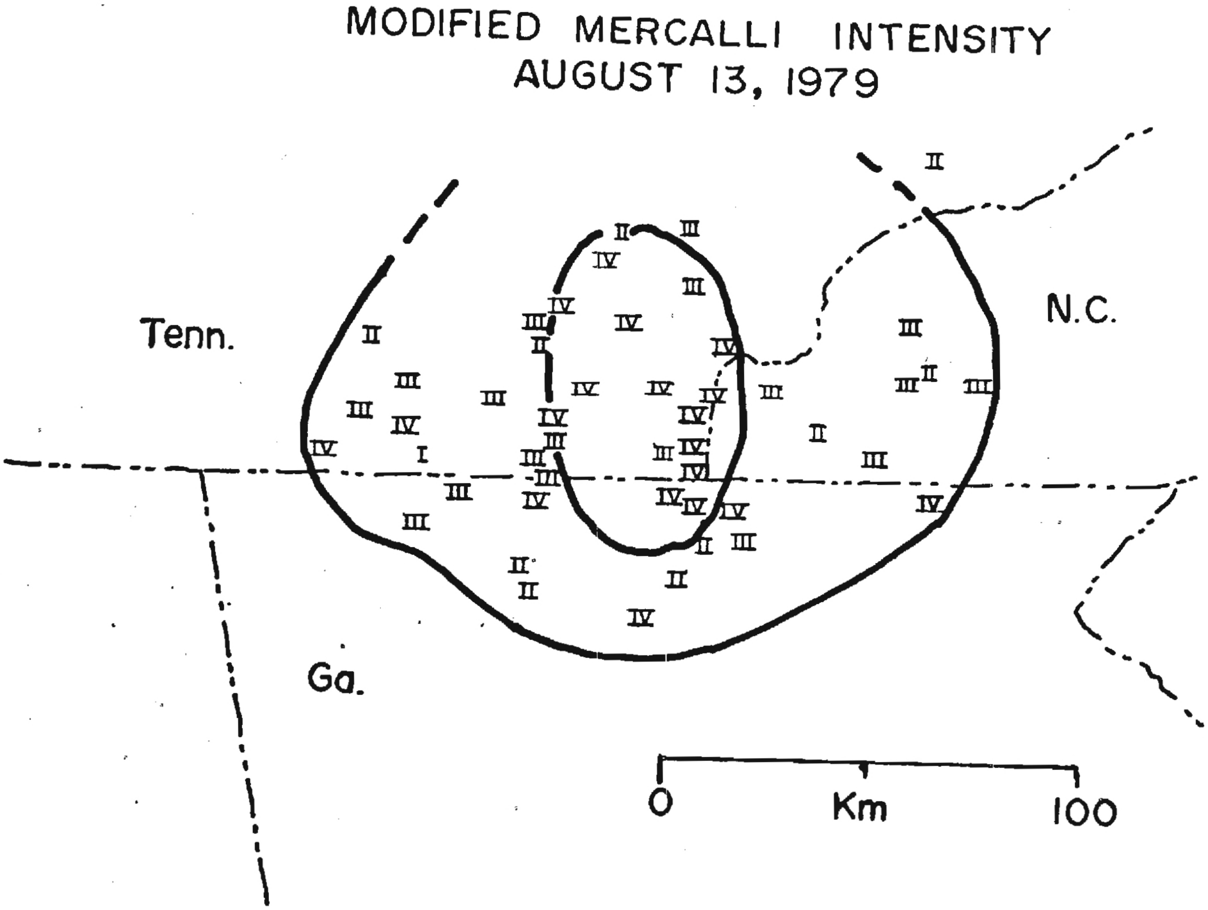

Figure 3. Distribution of Intensity Data (Modified Mercalli) for the August 13, 1979 earthquake in southeastern Tennessee.

Table 1. Summary of Intensity Data for the southeastern Tennessee event of August 13, 1979

City	County	State	Avg.	I	II	III	IV	V
				Intensity(ies)				
Copperhill	Polk	TN	III			1		
Old Fort	Polk	TN	III			1		
Murphy	Cherokee	NC	III		1	1	3	
Blue Ridge	Fannin	GA	III			1	1	
Unaka	Cherokee	NC	III			1		
Cherrylog	Gilmer	GA	II		1			
Hiawasse	Towns	GA	IV				1	
Epworth	Fannin	GA	IV				1	
Ooltewah	Hamilton	TN	IV				1	
Townsend	Blount	TN	II		1			
Benton	Polk	TN	IV				1	
Ducktown	Polk	TN	IV				6	1
Postelle	Polk	TN	III			1		
McCaysville	Fannin	GA	IV				1	
Tobbinsville	Monroe	TN	III			1		
Mt. Vernon	Monroe	TN	III			1		
Farner	Polk	TN	IV				1	
Apison	Hamilton	TN	I	1				
Cisco	Murray	GA	IV				1	
Ellijay	Gilmer	GA	IV				1	
Daisy	Hamilton	TN	II		1			
Varnell	Whitfield	GA	III			1		
Andrews	Cherokee	NC	III			1		
Harrison	Hamilton	TN	III			1		
Brasstown	Caly	NC	III			1		
Chattanooga	Hamilton	TN	IV				1	
Madisonville	Monroe	TN	III			2	2	
Cleveland	Bradley	TN	III		1	2	3	
Mineral Bluff	Fannin	GA	IV				1	
Charleston	Bradley	TN	III			1		
Telico Plains	Monroe	TN	IV			3	8	2
Delano	Polk	TN	IV			1	3	
Ocoee	Polk	TN	IV				1	
Reliance	Polk	TN	IV				1	
Marietta	Cobb	GA	I	1				
Cohutta	Whitfield	GA	III			1		
Chatsworth	Murray	GA	II		1			
Eton	Murray	GA	II		1			
Etowah	McMinn	TN	IV				1	
Aquone	Macon	NC	III			1		
Niota	McMinn	TN	II		1			
Shelbyville	Bedford	TN	II		1			
Riceville	McMinn	TN	IV				1	
Topton	Cherokee	NC	II		1			
Decatur	Meigs	TN	I	1				
Calhoun	McMinn	TN	IV				1	
Tenngo	Murray	GA	III			1		
Coker Creek	Monroe	TN	IV		1	3	3	1
Athens	McMinn	TN	IV				2	
Conasauga	Polk	TN	III			1		
Morganton	Fannin	GA	III			1		
Mixson	Hamilton	TN	III			1		
Turtletown	Polk	TN	IV				2	

Table 2. Arrival times at regional seismic stations and location data for the August 13, 1979 earthquake.

	Phase	Station	Arrival Hr	Min	Sec	Error ± sec.
1	PLG	CDG	5	19	8.800	.100
2	SLG-PLG	CDG	0	0	8.800	.100
3	PLG	TVG	5	19	17.060	.100
4	PN	REG	5	19	31.100	.500
5	SN-PN	REG	0	0	25.040	.500
6	PN	CH6	5	19	31.200	.500
7	PN	EP1	5	19	31.150	.500
8	SN-PN	EP1	0	0	25.100	.500
9	PN	ETG	5	19	32.960	.500
10	PN	WDG	5	19	33.000	.500
11	SN-PN	WDG	0	0	25.560	.500
12	PLG	TKL	5	19	9.200	.100
13	SLG	TKL	5	19	18.200	.100
14	SLG-PLG	CPO	0	0	14.800	.100
15	PLG	SRN	5	19	50.500	1.000
16	SLG	SRN	5	20	28.300	1.000
17	PLG	SRW	5	19	51.800	1.000
18	SLG	SRW	5	20	32.000	1.000
19	PLG	SRD	5	19	50.000	1.000
20	SLG	SRD	5	20	30.800	1.000
21	PLG	SRN	5	19	52.000	1.000
22	SLG	SRN	5	20	28.200	1.000
23	PN	HBF	5	19	58.550	5.000
24	PN	SGS	5	19	54.950	5.000
25	PN	MTT	5	19	40.050	5.000
26	PN	LHS	5	19	45.400	5.000
27	PN	PRM	5	19	31.650	5.000
28	PN	CHF	5	19	29.950	5.000
29	PN	JSC	5	19	41.750	5.000
30	PN	SH1	5	20	4.500	5.000
31	SLG	SH1	5	21	11.300	5.000
32	PN	SH2	5	20	4.300	5.000
33	SLG	SH2	5	21	10.200	5.000
34	PN	SH3	5	20	5.700	5.000
35	SLG	SH3	5	21	12.100	5.000
36	PLG	BG3	5	19	20.170	1.000
37	PLG	LPM	5	19	18.900	1.000
38	PLG	SMT	5	19	20.140	1.000
39	PN	SRN	5	19	44.000	1.000
40	PN	SRW	5	19	45.300	1.000
41	PN	SRD	5	19	44.400	1.000
42	PN	SRN	5	19	43.400	1.000

Table 2. (Continued....)

STATION	PHASE	HR	MIN	SEC	+OR-SEC	DIST	AZ
CDG	PLG	5	19	8.80	.10	72.24	200.5
CDG	SLG-PLG	0	0	8.80	.10	72.24	200.5
TVG	PLG	5	19	17.06	.10	125.03	221.9
REG	PN	5	19	31.10	.50	219.27	153.6
REG	SN-PN	0	0	25.04	.50	219.27	153.6
CH6	PN	5	19	31.20	.50	224.72	130.6
EP1	PN	5	19	31.15	.50	221.41	129.0
EP1	SN-PN	0	0	25.10	.50	221.41	129.0
ETG	PN	5	19	32.96	.50	233.93	155.6
WDG	PN	5	19	33.00	.50	231.02	150.9
WDG	SN-PN	0	0	25.56	.50	231.02	150.9
TKL	PLG	5	19	9.20	.10	74.22	48.9
TKL	SLG	5	19	18.20	.10	74.22	48.9
CPO	SLG-PLG	0	0	14.80	.10	115.19	291.2
HBF	PN	5	19	58.55	1.00	444.96	124.0
SGS	PN	5	19	54.95	1.00	418.61	121.9
JSC	PN	5	19	41.75	1.00	303.64	109.9
LHS	PN	5	19	45.40	1.00	336.31	104.0
PRM	PN	5	19	31.65	1.00	223.50	124.0
CHF	PN	5	19	29.95	1.00	211.05	128.5

ERROR ELLIPSE IS AS FOLLOWS:
SEMIMINOR AXIS LENGTH = 1.5248 KM.
SEMIMAJOR AXIS LENGTH = 2.6873 KM.
AZIMUTH OF MAJOR AXIS = 143.7282 DEG.
AREA OF ELLIPSE = 12.8731 SQ.KM.
ECCENTRICITY = .8234

MEAN RESIDUAL : .30749 STANDARD DEVIATION : .53015 is equivalent to subtracting exactly 2.0 seconds from the arrival times of the Pn phases. The depth of the Moho in the vicinity of the August 13, 1979 event varies from 40 to 55 km deep on the basis of data from Kean and Long (1980). The depth computed for an assumed Moho at 49.6 km was 9.7 km ± 4.5 km. Interpolation of the Moho depth from Kean and Long (1980) on the basis of the revised epicenter indicate a 45 km Moho depth. Then correcting the 9.7 km depth of focus for the difference between a 45 and 49.6 km deep Moho gives 5.0 km ± 4.5 km depth. This estimate is consistent with a 6.0 km depth of focus found for one of the aftershocks (see discussion below). If one assumes a 6 km depth of focus for the main shock, then the method of Kean and Long (1980) implies a 46.5 km deep Moho which is consistent with their data for the north Georgia area.

Magnitude

The magnitude of the event was determined from duration data from ten stations. For these stations the duration ranged from 240 to 270 seconds. Using Bollinger's (1979) formula

$$m_b = 2.44 \text{ Log}_{10} D - 2.87$$

a magnitude of 3.0 was found. Using a similar formula from the U. S. Geological Survey which they apply to the South Carolina seismic network

$$m(D) = 2.0 \text{ Log}_{10}(D) - 1.5$$

the magnitude was 3.6. We will assume an average magnitude of M(D) = 3.3 ± 0.3 as a reasonable estimate for the August 13, 1979 main event.

Focal Mechanism

A study of the directions of first motion was made for 16 stations (Table 3). The first motions were then evaluated for the domain of valid focal mechanisms using a computer technique developed in Guinn and

Table 3. First Motion data for southeastern Tennessee earthquake of August 13, 1979.

AZIMUTH	TOA	1ST MOTION
44.400	65.000	1.00
204.900	65.000	1.00
151.400	42.000	-1.00
156.200	42.000	-1.00
154.100	42.000	-1.00
130.500	42.000	-1.00
292.300	65.000	1.00
123.700	42.000	-1.00
128.400	42.000	-1.00
123.900	42.000	-1.00
121.700	42.000	-1.00
11.000	65.000	1.00
84.400	42.000	-1.00
85.400	42.000	-1.00
84.900	42.000	-1.00
221.100	65.000	1.00

TYPE 1, SPACE TO TOP OF PAGE AND PRESS RETURN

? 1

Long (1977). The distribution of first motions is given in Figure 4. The valid P T and B axes for these first motions are shown in Figure 5. The P-axis is constrained by the data distribution to (S45°E, 70° dip) within 20°. Two dominant zones of B and T axis are allowed. These indicate fault plains as given in Table 4.

Table 4. Fault plains for focal mechanism solutions

	Strike	Dip
Solution 1	N65W	25 S
	N80E	65N
Solution 2	N70W	50NE
	N10W	55W

We interpret the data in table 4 to imply normal faulting on northwest trending faults. The normal faulting mechanisms differs from previous focal mechanism for southeastern Tennessee which indicate thrust faulting (see Guinn 1977). This event and previous events indicate faulting which is normal to the dominant trend of the near surface faults and geologic units which represent Paleozoic deformation.

Aftershock Study

Associated with this event were four aftershocks recorded at regional stations within four hours of the main event. The third of these was recorded at four stations in the Georgia Tech network and was independently located at 35°17.8'N, 84°30.7°W. Its origin time was at 5:36:28.6 ± 0.9 sec on August 13, 1979.

Within one day after the main event on August 13, 1979 the Tennessee Earthquake Information Center and Georgia Institute of Technology established a joint aftershock monitoring network consisting of four smoked paper recorders. Records were changed daily by Georgia

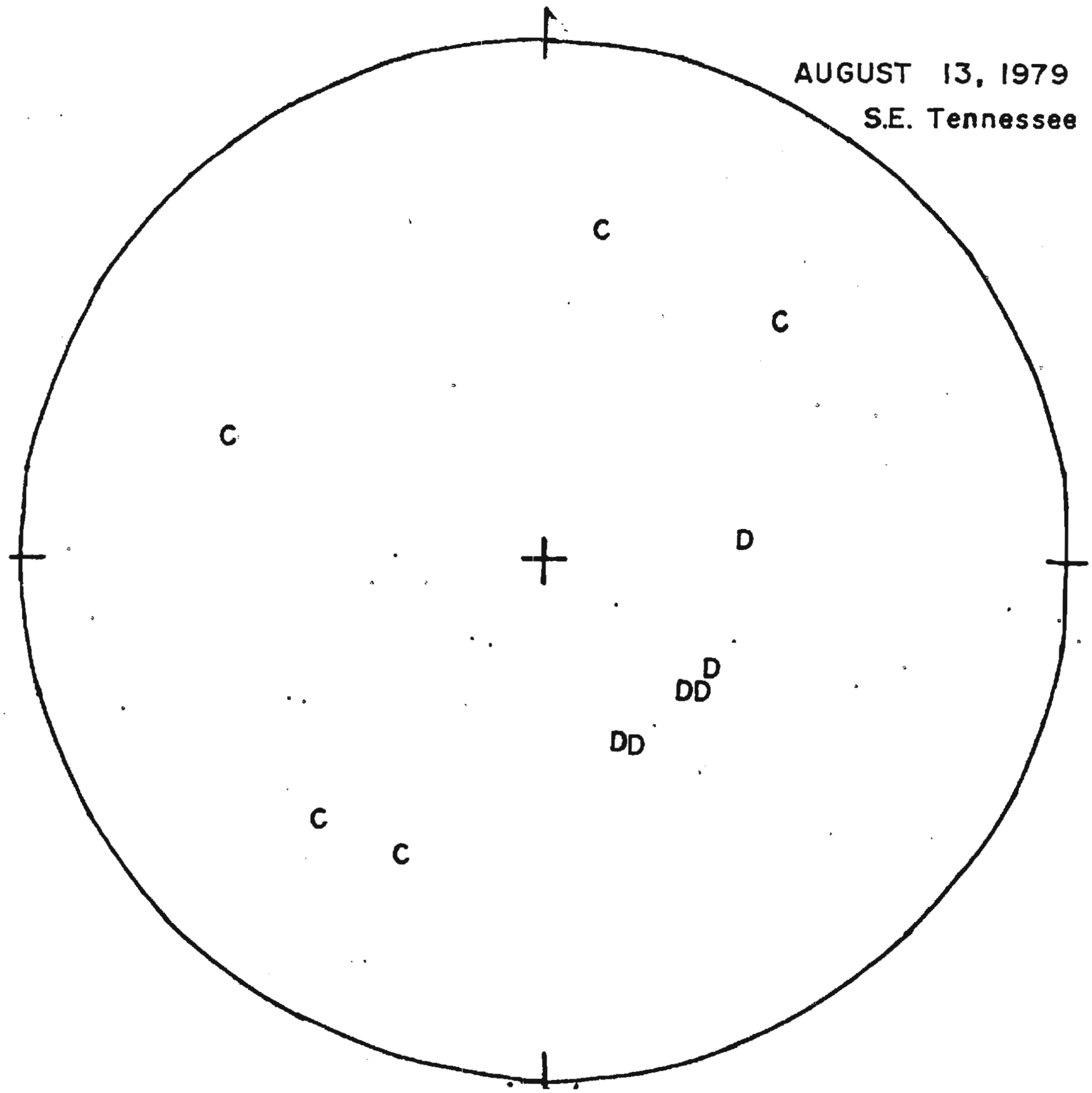

Figure 4. Lower hemisphere plot of first Motion data for the August 13, 1979 southeastern Tennessee earthquake.

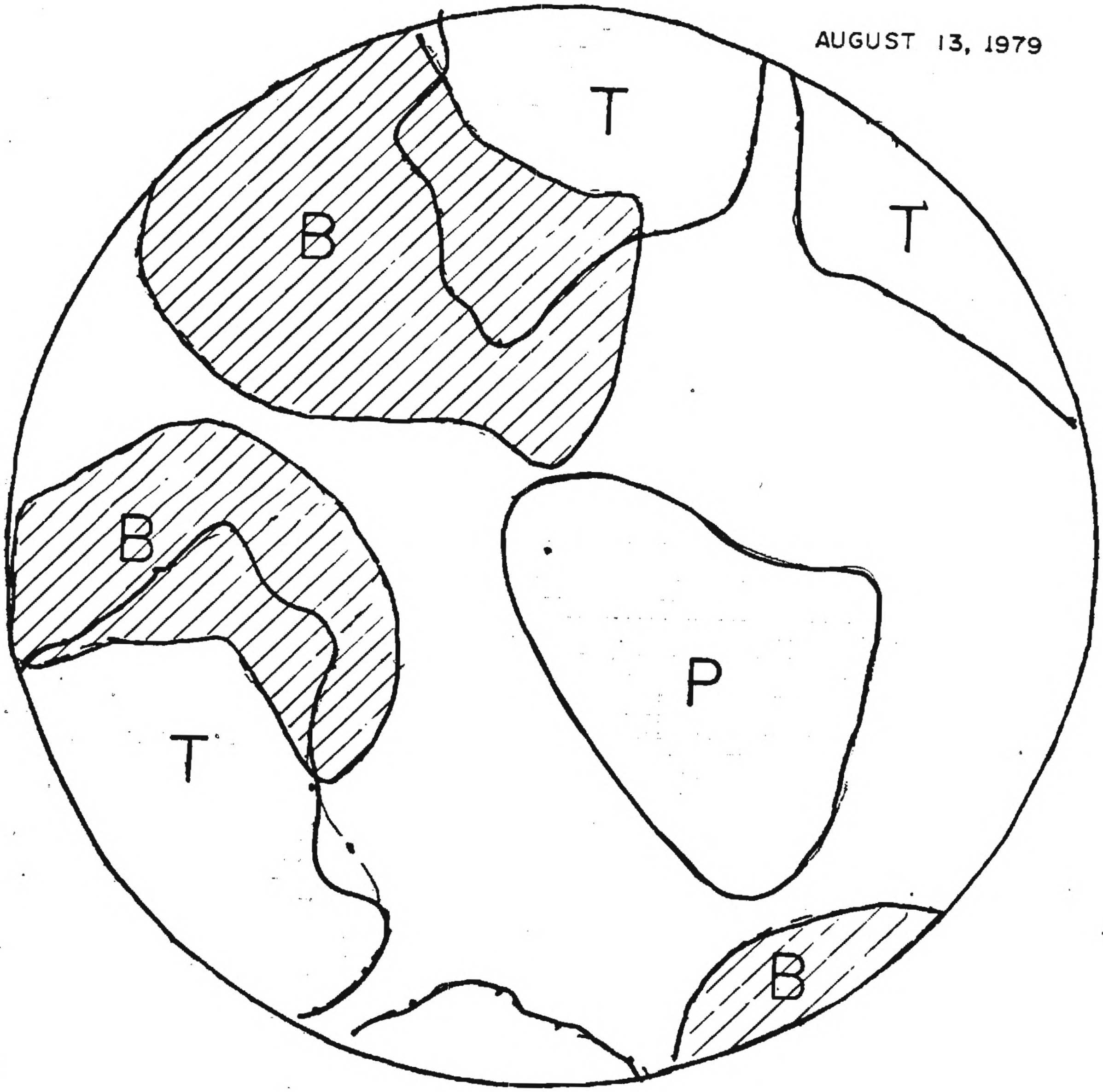

Figure 5. Lower hemisphere projection of valid P, T, and B, axis for the August 13, 1979 southeastern Tennessee earthquake.

Tech and Tennessee Valley Authority personnel for a period of one month and the timing was correlated with WWV daily. The stations were placed at locations surrounding the epicenter of the main event (see Table 6).

From August 14 to August 15, three possible aftershocks were recorded by these stations. One was recorded at only one station and was not located. The other two were located (see Table 5). The depth of focus for the aftershock occurring at 8:14:14.7 on August 15, 1979 was at 6.5 km. This value was used earlier to confirm the depth of the main event. After this aftershock, the temporary recording stations were relocated in order to better surround the epicenters of the recorded aftershocks (see Table 5).

These stations were operated for one month and during that time eleven possible aftershocks were recorded (see Table 6). Of these only

Table 6.

PLT	35°13'12.0"N,	84°27'37.5"W	1120 ft.
IVY	35°17'25.5"N,	84°26'43.5"W	1280 ft.
FCT	35°16'18.0"N,	84°22'18.0"W	1625 ft.
DRT	35°12'37.5"N,	84°21'45.0"W	1850 ft.

two were recorded at more than one station. During the aftershock monitoring period a magnitude 3.2 event was recorded on September 12, 1979. The event occurred near Maryville, TN. In addition, several teleseismic events and regional blasts were recorded.

Discussion of Results

The depth of focus of the events indicates a source in the basement rocks of the underthrust crust as interpreted from COCORP data (Cook). The focal mechanism deviates from past data and may indicate a highly non-uniform stress field in the crust. The depth of focus also may

Table 5. Listing of events recorded during the aftershock monitoring of the August 13, 1979 earthquake in southeastern Tennessee.

EVENTS RECORDED : GEORGIA TECH EAST TENNESSEE NETWORK (TEMPORARY)

AUGUST - SEPTEMBER , 1979

DATE	STA.	A.T.	S-P	T	O.T.	DIST.	LOCATION/COMMENTS
08/14	SMC	08:21:36.43	11.87	16.28	08:21:20.15	95.04	NOT LOCATED
08/15	SMC	02:27:54.10	1.76	2.94	02:27:51.16	15.12	LATITUDE=35.0153 (35D,00.92M) +/-3.438KM. NO DEPTH SEQUENCE
08/15	REL	02:27:54.30	2.68	3.14	02:27:51.16	18.24	LONGITUDE=84.4285 (84D,25.70M) +/-1.075
08/15	SMC	02:39:47.00	.85	1.17	02:39:45.83	6.83	NOT LOCATED; POSSIBLE BLAST
08/15	SMC	08:09:17.40	2.28	2.66	08:09:14.74	18.25?	STATION NOT USED IN LOCATION ROUTINE
08/15	LG2	08:09:17.76	2.22	3.02	08:09:14.74	16.62	LATITUDE=35.1519 (35D,09.11M) +/-.043KM. NO DEPTH SEQUENCE
08/15	REL	08:09:17.75	2.19	3.01	08:09:14.74	16.51	LONGITUDE=84.3322 (84D,19.93M) +/-.056KM.
08/22	DRT	02:53:34.10	2.36	3.23	02:53:30.87	18.86	NOT LOCATED
08/22	DRT	05:30:18.45	2.49	3.41	05:30:15.04	19.88	NOT LOCATED
08/26	IVY	01:32:09.62	19.50	24.61	01:31:45.01	150.88	JOCASSEE, S.C. EVENT (MAGNITUDE 3.7)
08/26	FCT	01:32:09.38	18.60	24.37	01:31:45.01	142.94	LATITUDE=34.8471 (34D,50.80M) NO DEPTH SEQUENCE
08/26	DRT	01:32:08.13	19.00	23.12	01:31:45.01	139.12	LONGITUDE=82.9467 (82D,56.80M)
08/26	IVY	03:40:04.45	3.70	1.70	03:40:02.75	24.82	LATITUDE=35.4946 (35D,29.67M) +/-11.07KM.
08/26	DRT	03:40:06.70	3.85	3.95	03:40:02.75	30.77	LONGITUDE=84.4026 (84D,24.15M) +/-2.739KM.
08/29	FCT	01:15:46.45	2.36	3.23	01:15:43.2	18.86	NOT LOCATED; POSSIBLE AFTERSHOCK
08/30	DRT	06:14:53.98	2.93	4.02	06:14:49.96	23.45	NOT LOCATED; POSSIBLE AFTERSHOCK
08/31	DRT	06:26:18.79	2.38	3.27	06:26:15.52	19.07	NOT LOCATED
09/01	FCT	23:16:30.06	3.00	4.11	23:16:25.95	23.99	NOT LOCATED
09/04	PLT	04:18:36.54	3.01	4.12	04:18:32.42	24.07	NOT LOCATED
09/09	FCT	16:57:26.42	3.44	4.71	16:57:21.71	27.53	NOT LOCATED
09/09	DRT	12:11:19.80	.47	.65	12:11:19.15	3.77	NOT LOCATED
09/11	IVY	03:43:30.88	?	?	?	?	NOT LOCATED; APPARENT TIMING ERRORS;
09/11	PLT	03:43:38.13	?	?	?	?	ONLY ONE POSSIBLE PG PHASE OBSERVED
09/11	DRT	03:43:48.36	.80	1.01	03:43:55.35	5.91	
09/11	FCT	03:43:53.28	?	?	?	?	
09/11	IVY	04:25:31.13	10.50	12.85	04:25:18.28	77.35	LATITUDE=35.9428 (35D,56.57M) +/-15.235KM. DEPTH=8.00KM.
09/11	FCT	04:25:31.47	11.00	13.19	04:25:18.28	82.74	LONGITUDE=84.7256 (84D,43.54M) +/-5.896KM.
09/11	PLT	04:25:32.74	10.75	14.46	04:25:18.28	84.15	
09/11	DRT	04:25:32.87	12.00	14.59	04:25:18.28	88.21	
09/12	IVY	06:24:14.00	6.60	8.17	06:24:05.19	48.28	LATITUDE=35.4938 (35D,29.62M) NO DEPTH SEQUENCE
09/12	FCT	06:24:13.46	?	7.63	06:24:05.19	43.89	LONGITUDE=83.9175 (83D,55.05M)
09/12	PLT	06:24:16.59	7.15	10.76	06:24:05.19	55.03	STATIONS FCT, DRT SATURATED
09/12	DRT	06:24:14.58	?	8.75	06:24:05.19	50.57	MARYVILLE EVENT

NOTES:
1. ALL DISTANCES ARE IN KILOMETERS.
2. S-P, T ARE GIVEN IN SECONDS.
3. IF AN EVENT WAS NOT LOCATED, T, DIST. ARE ARRIVED UPON AS FOLLOWS:
   T=1.37(S-P) DIST=8.0(S-P)

explain why the maximum intensity was limited to IV(MM). Additional data are needed to clarify these results.

Acknowledgments

The Tennessee Earthquake Information Center provided coordination and assistance in establishing the aftershock monitoring program and also provided one of the portable instruments used in the monitoring. The aftershock monitoring was largely made possible by a grant from the Tennessee Valley Authority. Don Reinbolt of TVA assisted generously in the field work.

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A GEOPHYSICAL INVESTIGATION OF THE SEISMICITY OF THE CLARKS HILL RESERVOIR VICINITY

Quarterly Progress Report 20
March 1, 1980 to May 31, 1980

Leland Timothy Long
School of Geophysical Sciences
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Report Due Date May 31, 1980
Submitted August 1980

PREPARED FOR THE U.S. NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR REGULATORY RESEARCH
UNDER CONTRACT NRC-04-77-211

A Geophysical Investigation of the Seismicity of the
Clarks Hill Reservoir Vicinity

Quarterly Progress Report No. 20

Abstract

Seismic monitoring continued at stations CH5, CH6, and intermittently EPI during the quarter. A swarm of events starting in April appears to be related to a six-foot increase in water level early in March. Seismic monitoring at station ETA continued during the period. An analysis of the seismicity in the vicinity of ETG in central Georgia is nearing completion as a thesis topic by Jerry Allison.

Scope of Investigation

To determine the relation between geology and seismicity and to determine the tectonic environment that is responsible for earthquakes in the Clark Hill Reservoir vicinity by continuing to monitor seismic activity rates versus water level in the Clark Hill Reservoir area and to locate seismic events. During periods of increased activity, portable instruments will be used to compute locations, focal mechanisms and spectral signature. Stations CH5 and CH6 will be maintained in continuous operation. Three RF stations will be operated in the area of the earthquake of August 2, 1974 (Mag. 4.3) to provide locations and origin times for the continuing aftershocks. Data from these stations will be coordinated with proposed U.S. Corps of Engineers net in the Richard B. Russell reservoir area. One station will be maintained (ETG) to monitor the activity near Lake Sinclair in conjunction with continued operation of the Wallace Dam net WDG (expanded to 3-component) GBG, REG and one new station to improve location of events in the Lake Sinclair area. A suite of four portable smoked paper recording seismographs will be used intermittently in areas of special interest. Areas of special interest will be surveyed using the direct current electrical resistivity sounding to typical depths of the earthquakes (0.5 to 1.0 km) to determine penetration by ground water. Areas in the yet unfilled Richard B. Russell reservoir area (directly north of CHRA) will be similarly surveyed.

Results of Investigation During Quarter

Recording Summary: Seismic monitoring continued without major interruption at CH5 (Double Branches) in the southern part of the reservoir and at CH6 (near Goshen in the northern part of the reservoir). EPI in the epicenter area of the 2 August 1974 earthquake operated for the period of April 10, 1980 to May 16, 1980

A log of seismic activity was maintained for the Clarks Hill Reservoir vicinity and the aftershock zone of the 2 August 1974 earthquake. Figure 1 shows the number of events recorded at CH6 (or its equivalent) versus water level. One swarm of activity occurred in the aftershock zone of the 2 August 1974 earthquake during April. This swarm occurred approximately one month after a five-foot increase in water level and at the same time as a rapid four-foot decrease in water level.

Two possible small earthquakes occurring outside the aftershock zone were detected on March 19, 1980. Both were located near the southwestern portion of the reservoir in an area near where very minor activity has been previously detected (33.75 N, 82.39 W).

Station ETG recorded continuously in the Lake Sinclair area (see Figure 2 for locations) in cooperation with the Wallace Dam Seismic Net funded by Georgia Power. Events located during this quarter in the Lake Sinclair area are shown in Figure 2. Figure 3 shows the locations of a swarm of microearthquakes located in the Lake Oconee area. These microearthquakes were characterized by low magnitude (less than 0.0). These events are the only events detected to date in the Lake Oconee area, after impoundment over one year ago.

All of the local and regional data recorded at stations operated out of Georgia Tech have been made available for publication in the Southeastern United States Seismic Network Bulletins.

Resistivity Studies: On May 16-17, 1980 three depth soundings were obtained using the Schlumberger configuration. The third, however, was interrupted by inclement weather. A profile was obtained across the epicenter area at an array spread of AB/2 = 20 meters. The profile will be repeated later with array spreads of AB/2 = 100, and 400 meters later.

Progress During Quarter: Progress during the quarter was limited to resistivity fieldwork and the analysis of recorded events.

Efforts Expended During Quarter: The principal investigator expended an average of 20 percent time on the project during the quarter. One graduate student was supported at the rate of 50 percent time and one electronics technician at 15 percent time.

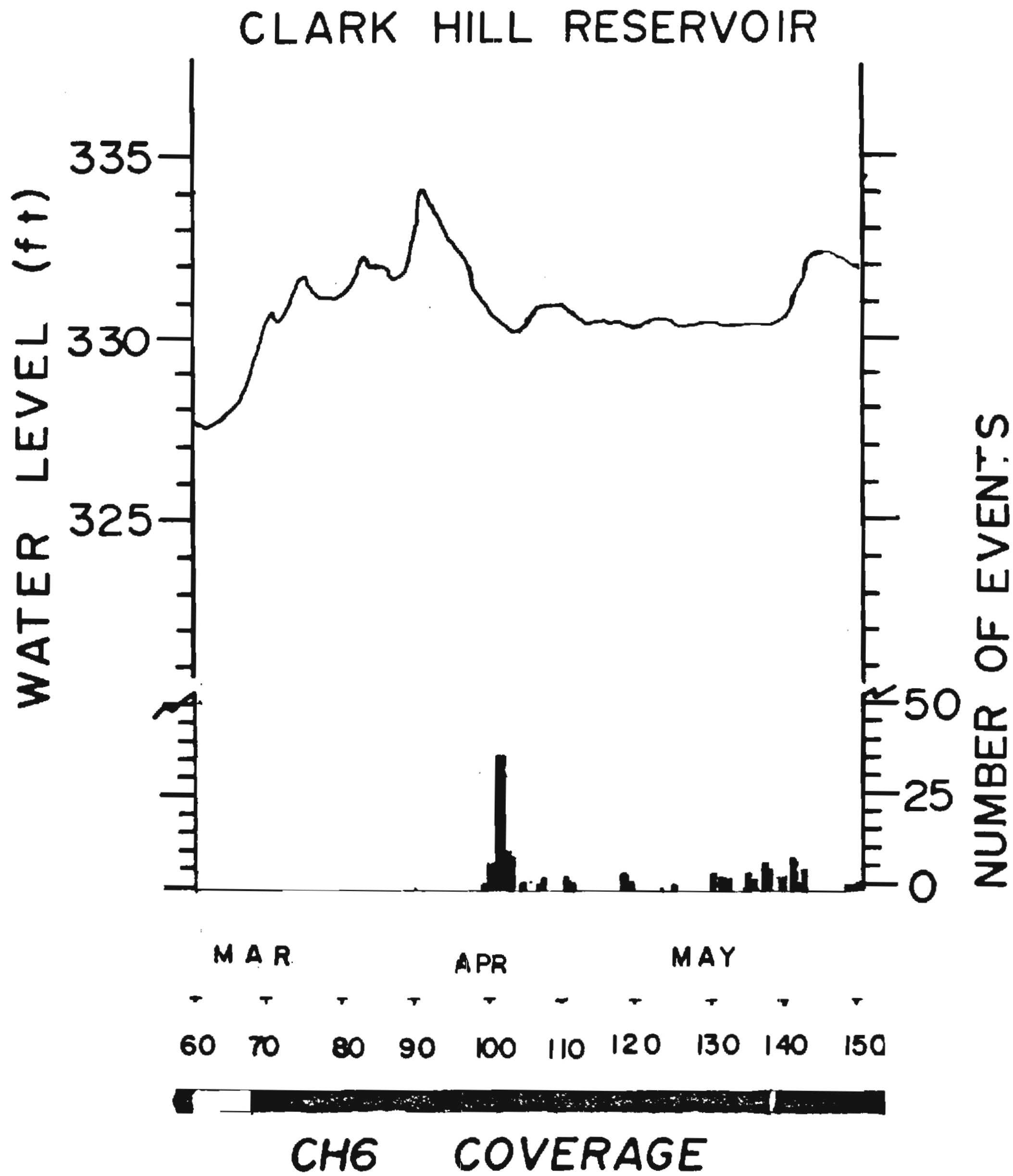

Figure 1. Log of activity versus water level for the Clark Hill Reservoir area.

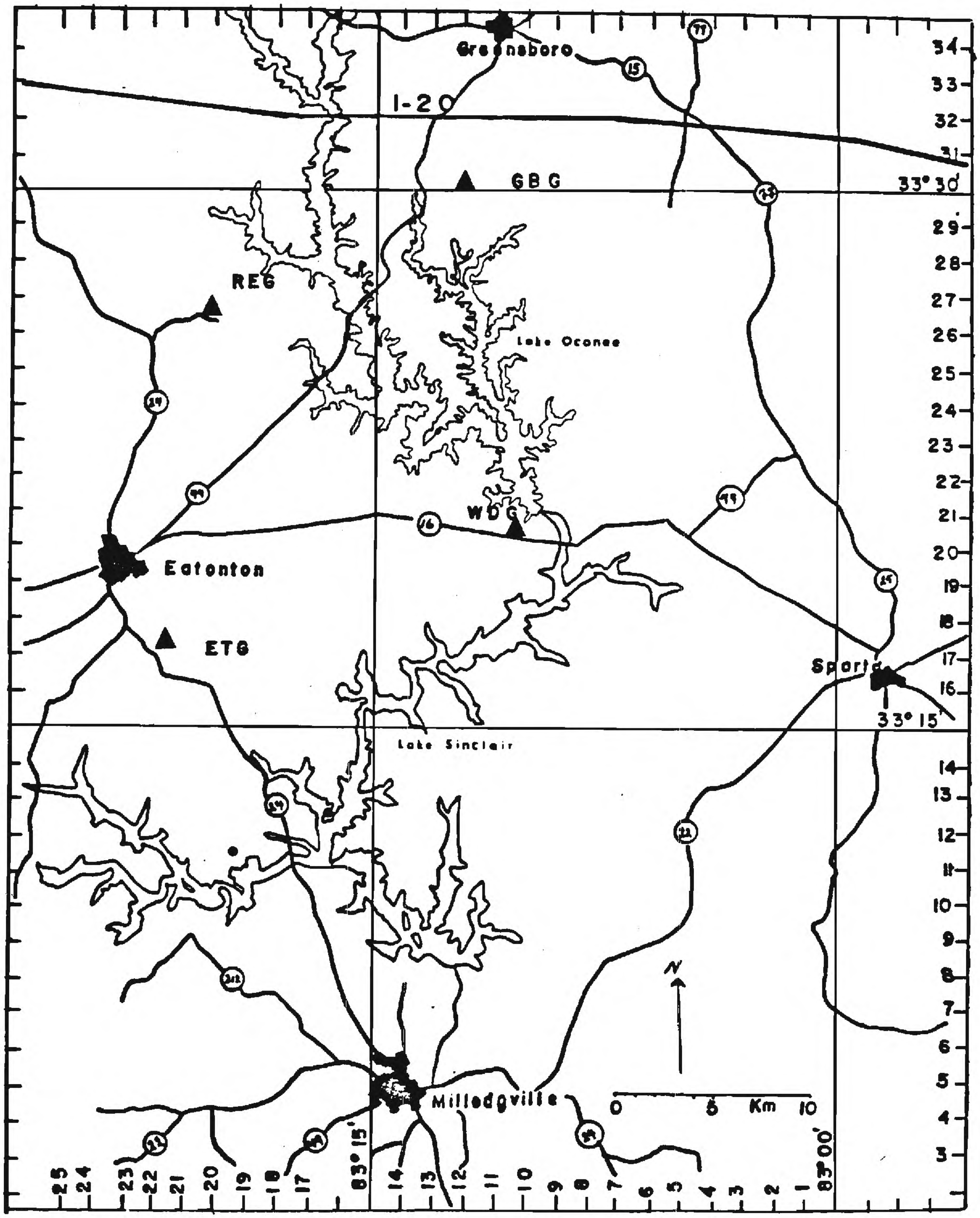

Figure 2. Earthquakes located in the Lake Sinclair region with the help of station ETG. Dots indicate earthquake location.

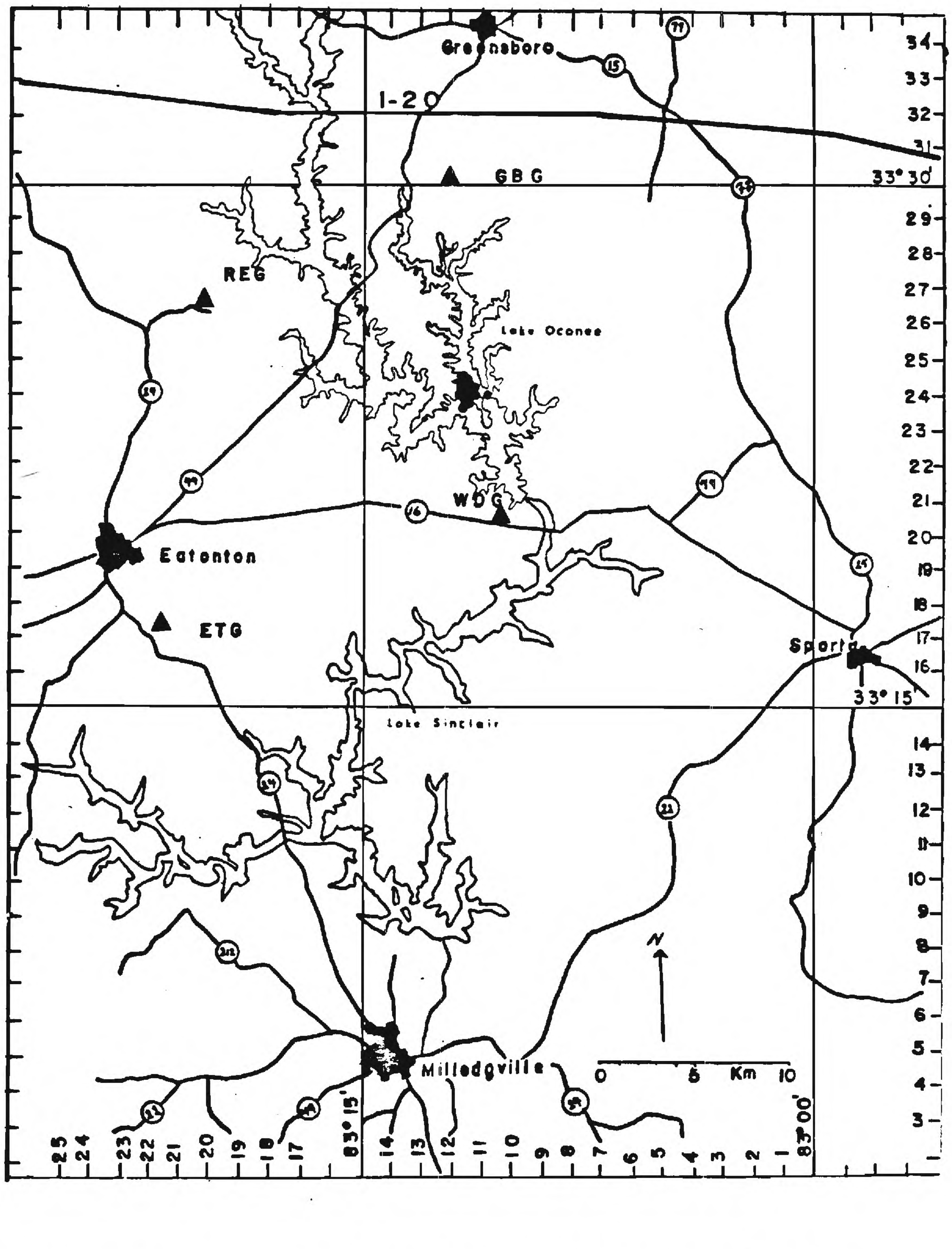

Figure 3. Microearthquake location in the Lake Oconee region located with the help of station ETG. Dots indicate microearthquakes location.